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# Violation of the Equivalence Principle and the Boundary of Einstein's General Relativity

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**Abstract:** *The article discusses the expected progress in understanding the fundamental laws of nature and assesses the promise of recent gravitational-cosmic experiments. New theoretical models include new types of interaction that can lead to violation of the equivalence principle, variations of fundamental constants, and violation of the Lorentz symmetry. This determines the limits of applicability of the invariant equations of Einstein's general relativity.*

**Keywords:** *gravitational mass; inert mass; dark matter; quantum vacuum*

## 1. Introduction

It is known that the work on the creation of general relativity Einstein began with the principle of equivalence (PE), in which he postulated that gravitational acceleration is indistinguishable from the acceleration caused by mechanical forces [1]. As a consequence, the gravitational mass became in A. Einstein under any conditions equal to the inertial mass. Galileo in 1602-1604, after conducting a series of experiments with inclined planes and pendulums, formulated the law of falling bodies, which became the first empirical version of the PE. Newton in his "Beginnings" in 1687 on the basis of his second law came to the conclusion that the gravitational force is proportional to the mass of the body to which it acts. At the same time, Newton knew that the inert mass $m_i$, which appears in his second law $\mathbf{F} = m_i\mathbf{a}$, can differ from the gravitational mass mg related to the force of the gravitational field $\mathbf{F} = mg\,\mathbf{g}$. Indeed, comparing the two equations, we get that $\mathbf{a} = (mg / m_i)\, g$ and, in principle, bodies with different values of the ratio $(mg / m_i)$ could receive a different acceleration $\mathbf{a_r}$ in the same gravitational field. Newton checked this possibility on simple pendulums of the same length, but with different masses and composition of the load, but did not discern any differences in the period of their oscillations. On this basis, he concluded that the value $(mg / m_i)$ is a constant and with a proper choice of the system of units, this ratio can be reduced to unity, that is $(mg / m_i) = 1$. In 1899, the decisive numerous experiments by R. von Eötvös showed the equality of the inertial and gravitational masses to within $10^{-9}$. Einstein raised this equality to the level of a leading postulate in his attempts to explain both electromagnetic and gravitational acceleration by the same physical laws. This principle predicts the same acceleration for bodies of different composition in the same gravitational field and allows us to consider gravity as a geometric property of space-time, which leads to the interpretation of gravity from the positions of the General Theory of Relativity Checks of the equivalence principle can be carried out by comparing the free-fall acceleration $\alpha_r$ of various test bodies. When the bodies are at the same distance from the source of gravity, the expression for the PE acquires a compact form:

$$\frac{\Delta\alpha}{\alpha} = \frac{2(\alpha 1 - \alpha 2)}{\alpha 1 + \alpha 2} = \left[\frac{mg1}{m_i 1}\right] - \left[\frac{mg2}{m_i 2}\right] = \Delta\left[\frac{mg}{m_i}\right] \tag{1}$$

There are two formulations of the equivalence principle - a weak and strong form of PE. The weak PE form asserts that the gravitational properties of strong and electroweak interactions obey PE. In this case, the experimental bodies are composed of different materials with different nuclear bonds, the ratio of the number of neutrons to protons, atomic charges, and so on. Equality of the gravitational and inertial masses implies that different neutral bodies will have the same acceleration of free fall in the external gravitational field.

At present, the most accurate result in testing the weak form of PE belongs to the space experiment "MicroSCOPE" [3]. Researchers from the French aerospace research center ONERA and the Cote d'Azur Observatory in an experiment conducted on the MICROSCOPE satellite performed a PE test with a record accuracy of $\Delta \sim 10^{-14}$ [3]. On board the satellite there were two hollow coaxial cylinders, freely suspended in weightlessness. The inner cylinder is made of an alloy of platinum and rodney, and the outer cylinder is made of an alloy of titanium, aluminum and vanadium. For control there was a second same system, but with cylinders of the same material (alloy Pt and Rh). With the help of electrostatic sensors, the forces necessary to keep the inner and outer cylinders stationary relative to each other were measured. The presence of a signal that was modulated with the satellite's rotation frequency would indicate a violation of the PE. Such a violation was not found and the Eötvös parameter was limited to $\delta$ ($T_i$, Pt) = [-1 ± 9 (stat.) ± 9 (syst.)] $\times 10^{-15}$. This result an order of magnitude improves the previous limitation and was extended to planetary-sized bodies. The accuracy of these data is high enough to confirm that strong, weak and electromagnetic interactions give the same contribution to the gravitational and inert mass of the body. GRT and other metric gravity theories believe that the weak form of PE is correct, however, many extensions of the Standard Model containing macroscopic quantum fields predict a violation of the weak PE shape [1,4]. In the article [4] Yu.A. Baurov showed that part of the mass of an elementary particle is proportional to the modulus of some total potential $\bar{A}\Sigma$. The change in the $\bar{A}\Sigma$ module due to the potentials of other fields ($\Delta\bar{A}\Sigma$) should lead to the appearance of a new force of nature (the fifth type of interaction), which is non-linear and non-local in nature. It can be represented by some series in $\Delta\bar{A}\Sigma$. In this case, the first term of the series in the decomposition in $\Delta\bar{A}\Sigma$ has the form $\sim \Delta\bar{A}\Sigma \cdot \partial\bar{A}\Sigma / \partial x$, where x is the spatial coordinate in the three-dimensional space R3 [4].

The strong equivalence principle is expanded so as to include the gravitational properties that result from its own gravitational energy, that is, the nonlinear properties of gravity. In view of the extreme weakness of gravity, test bodies to test the strong principle of gravity must have astronomical dimensions. To date, the Earth-Moon-Sun system seems to be the best model in the solar system for testing the strong PE shape. Experiments of the laser rangefinder of the Moon (LRM) were associated with the reflection of laser beams from an array of angular reflectors mounted on the moon by astronauts of the Apollo program and Soviet lunar rovers. The latest experimental data made it possible to establish that the possible inequality with respect to gravitational and inertial masses for the Earth and the Moon has a value $(0.8 \pm 1.3) \times 10^{-13}$ and although GRT believes that the PE is in strong form is not violated, alternative gravity theories using scalar fields predict a violation of strong PE [1]. For nonequilibrium systems, when irreversible processes are realized, the fifth interaction appears, connected with the influence of the scalar field of the quantum vacuum (dark matter). In this case, the value of the inertial mass of the body begins to differ from the value of the gravitational mass, which leads to violation of the equivalence principle. The article deals with the violation of both weak PE and strong PE. In this case, the violation of a weak PE is demonstrated on the examples of Kozyrev's and Dmitriev's laboratory experiments, and a strong PE on the example of the nonequilibrium system of the Sun - Mercury. Unlike the equilibrium system Earth-Moon-Sun, considered the best model in the solar system for testing the strong form of PE associated with the experiments of the laser far-range of the Moon (LRM) $\Delta$ ($m_g$ / $m_i$) $\sim 10^{-13}$, the nonequilibrium Sun-Mercury system made it possible to establish the difference in the ratio of gravitational and inertial masses for Mercury is about 1% or $\Delta$ ($m_g$ / $m_i$) $\sim 10^{-2}$.

It should be noted that although PE has had a great influence on the development of general relativity, it cannot be called a fundamental principle of relativity; therefore, within the framework of this article, we shall confine ourselves to identifying the limits of general relativity associated with PE, and this concerns experiments connected with active influence on the system from the outside, from the side of the quantum vacuum (dark matter). Based on the investigation of PE for objects involved in irreversible processes in nonequilibrium systems, the description of which is impossible with the help of the invariant equations of general relativity of Einstein, it was possible to delineate the limits of applicability of general relativity, within which the equivalence principle holds.

## 2. The Kepler's Constant and Violating Strong PE for the Planet Mercury

Johannes Kepler formulated his laws of celestial mechanics on the basis of analysis of long-standing astronomical observations of Tiho de Braga in 1609-1619. These are the laws:

1. All the planets move in elliptical orbits, one of the focuses of which is the Sun;

2. The area described by the radius vector of the planets is proportional to time;

3. The squares of the periods of rotation of the planets refer to each other as cubes of their large semi-axes of elliptical orbits, along which they rotate around the Sun [5].

Using Kepler's laws, it is possible to determine the elliptical orbit of any planet of the Solar system or the satellite of the Earth and all its parameters. In this case, analyzing the third law, one can obtain Kepler's constant (K) and calculate its value for all planets of the Solar system:

$$K = \frac{R^3}{T^2} \quad (2)$$

Where R is the average distance from the center of the planet to the center of the Sun,

T is the time of the complete revolution of the planet around the Sun

Isaac Newton fifty years later received Kepler's third law, as a consequence of the law of universal gravitation and the second law of dynamics, introducing into the spatial model of the universe the forces of gravity and inertia. This was a brilliant confirmation of the correctness of Newton's theory of gravitation.

$$K = GM\frac{m\,g}{m\,i} = \frac{R^3}{T^2}. \quad (3)$$

Where

m g. is the planet gravitational mass, interacting with the Sun, the M mass, produces a centripetal force of gravity;

m i. is the inertial mass of the planet. It is rotating around a circle of R radius and producing a centrifugal force of repulsion,

R is a distance from the centre of the planet to the centre of the Sun,

T is a period of the planet rotation around the Sun,

G is the gravitational constant,

K is Kepler's constant.

It should be noted that the Newton equation and the Kepler law are identical only under the condition of the existence of a stationary inertial motion of the systems. Motion of test bodies according to Kepler's laws is just an accelerated, but inertial motion - motion of bodies alonginertial trajectories, under which the principle of equivalence is fulfilled and the equations of general relativity are applicable. [6]. At the same time, the influence on the motion of planets along orbits from the outside (from the side of dark matter) is minimal. However, to describe non-inertial trajectories, when the test body passes into a nonequilibrium state, the invariant equations of general relativity are not used correctly. In this case, the principle of the equivalence of masses is violated. And Newton's equation can be used. This is easy to prove by comparing the value of Kepler's constant for Mercury and the planets of the Earth group (Venus, Earth, Mars). Johannes Kepler calculated the value of the constant K for 8 planets:

Earth, Venus, Mars $K = 3{,}35 \cdot 10^{24}\ km^3 \cdot year^{-2}$

Saturn, Jupiter, Uranus $K = 3{,}34 \cdot 10^{24}\ km^3 \cdot year^{-2}$

Mercury, Pluto $K = 3{,}33 \cdot 10^{24}\ km^3 \cdot year^{-2}$

Note the difference in the meaning of Kepler's constant. For planets of the terrestrial group, rotating along stable, slightly perturbed orbits, K = 3.35, and for Mercury, whose orbit is subject to strong perturbations due to its proximity to the Sun, the value of K = 3.33, that is, 1% less. Since the mass of the Sun (M) and the gravitational constant (G) for all planets in formula (3) is unchanged, the difference in the value of K can be explained only by the inequality of the ratio of the gravitational mass to the inertial mass, that is, a violation of the equivalence principle:

$$\left[\frac{\text{mg Earth}}{\text{m}_i\text{ Earth}}\right] \neq \left[\frac{\text{mg Mercury}}{\text{m}_i\text{ Mercury}}\right]; \quad \Delta(mg/m_i) \sim 2\cdot 10^{-2} \quad (4)$$

The development of the theory of superfluid media allowed us to consider phase transitions in dark matter models, similar to phase transitions in superfluid $^3He$-B. In her model of the superfluid physical vacuum , L.Boldyreva significantly expanded the analogy between the properties of superfluid $^3He$-B and the cosmic medium (dark matter), mainly due to inclusion of the properties of vortices: spin and electric polarization of medium in vortices, inertial properties of vortices and superfluids spin currents between them [7]. Perhaps the reason for the growth of the inertial mass is the disturbance of dark matter caused by the nonequilibrium state of Mercury when moving along the orbit when the velocity vector of the planet is constantly changing, forming vortices in the medium. The pressure in the vortex region formed behind the planet will become lower, which in turn will cause an increase in drag and, as a result, an additional inertia field [8]. Although the expansion of the analogy between the physics of condensed matter (superfluid $^3He$-B) and cosmology indicates the possibility of a nondissipative motion of celestial bodies under laminar motion, in turbulent motion, the ratio of the frictional resistance to the pressure resistance, described by the Reynolds number (Re), is the determining factor. The larger the Re, the greater the role of the drag and the more disturbed the equilibrium state of the system. Winner of the Nobel Prize Ilya Prigozhin called this effect “an active influence on the system from the outside, with the transition of the system in a nonequilibrium state.” In the work "Time of chaos, quantum" I.Prigozhin wrote: "In a stable stationary state, an active influence on the system from the outside is negligible, but it can become very significant if the system goes into a nonequilibrium state. In at the same time, the system becomes non-integrable, time loses the property of invariance and its behavior has a probabilistic character "[9]. Thus, by examining the nonequilibrium Mercury-Sun system, one can conclude that the strong equivalence principle has violated the planet Mercury and delineate the boundaries of general relativity within the framework of the, the equilibrium systems of the Moon-Earth-Sun. To them, apparently, you can attach the planets of the terrestrial group Venus and Mars.

## 3. The Calculation of the Motion of the Perihelion of Mercury and the Einstein's Error

The theory is completely useless if it is not confirmed by experiment. From the time of Einstein to verify the reliability of the theory of gravity, the calculation of the motion of the perihelion of Mercury was used. It has long been known in astronomy that because of its proximity to the Sun and under the influence of the gravity of other planets, Mercury is moving not just along an ellipse, but an ellipse which itself slowly rotates in 575" within a hundred years. This is an abnormal precession for the planets of the solar system. The corrections calculated on the basis of Newton's theory gave a rotation of the perihelion 532". It is believed that the remaining value of 43"cannot be explained within the framework of Newton's theory. This is not quite true. The sun makes a complete revolution around its axis in about 30 days. Therefore, it will necessarily be slightly oblate (like the Earth). Then the gravitational field of the Sun will depend on the angle (there is no spherical symmetry), and the trajectory of Mercury will necessarily make a turn. It's hard to say that this offset will be 43", but it will definitely be [10]. In 2015, calculation of the precession of the perihelion of the orbit of Mercury in the framework of the law of universal gravitation of Newton was carried out by the scientific collaborator of the Russian Academy of Sciences N.V. Kupryaev [11]. Calculations were carried out with increased accuracy of calculation and with an iteration step of 0.0005 s. N.V. Kupryaev showed that the average precession of the perihelion of the orbit of Mercury for 100 years in the framework of the law of universal gravitation of Newton is + 553". This is more by 21" of the generally accepted value of + 532", but less by 22 " of the observed value of + 575". This proves that, within the framework of the law of universal gravitation, the most reliable data are obtained for the precession of the perihelion of Mercury.

In 1915 A.Einstein calculated the precession of the perihelion of the orbit of Mercury and obtained the expected value 43", using the field equations of general relativity [2], it became his triumph. However, in 2013 it turned out that Einstein made a mistake in his calculations. In the United States and China, in 2013, a joint collection of "Unsolved Problems in Special and General Relativity" [12], Chief Editor Prof. Florentin Smarandach USA which can be called the Requiem for the Special and General Theories of Relativity. It contains 21 articles, one of them from the United States and one from Russia, and the rest from China. The collection opens with an article by Chinese mathematician Academician Hua Di "The explanation of the motion of the perihelion of Mercury by Einstein" [12, p. 5]. Academician Hua Di showed that, in calculating the precession of the perihelion of the orbit of Mercury, Einstein made a gross error in the integration. As a result, the result was 71.5", and not 43". In this story, it is alarming that in some later editions of Einstein's paper in formula (3), the coefficient 0.5 appears in square brackets in front of the integral and the result of the calculations becomes closer to 43" [12].

The motion of the planets of the solar system, and in particular the anomalous precession of Mercury's perihelion, can be influenced by the scalar field of the quantum vacuum (dark matter). Arthur Eddington in his book “Space, Time, Gravitation” notes that during one revolution of the planet, its orbit turns into a fraction of the total turnover, equal to a fraction:

$$d = 3\frac{v^2}{c^2} \quad (5)$$

Where v is orbital velocity of the planet

This result, with an accuracy of one angular second, corresponds to astronomical observations [13]. The ratio (5) given by Eddington must be related to the new fifth interaction and violation of the equivalence principle, since the orbital velocity of Mercury depends on the external action of the quantum vacuum (dark matter) [4,8].

## 4. Experiments

### 4.1. Kozyrev's and Rykov's Experiments on the Violation of Weak PE

In the article by professor N.A. Kozyrev “On the possibility of reducing the mass and weight of bodies under the influence of active properties of time” [14], the change in the inertial mass of bodies and the violation of PE in irreversible processes accompanying absolutely inelastic collision of bodies are presented. Inelastic impact is possible only in the case when there is a process of restructuring the structure of bodies, absorbing their mechanical energy. The process of restructuring the internal structure of bodies must develop with active participation from the outside from the side of dark matter and influence the value of the inert mass of bodies. Kozyrev's experiments showed that when the bodies are struck with irreversible deformation, their weight decreases. In this case, the decrease in weight does not disappear immediately after the end of the collision process, but it remains and decreases gradually with a relaxation time of the order of 15-20 min. In experiments with the impact of an elastic body (steel ball) on an inelastic plate (lead plate) the weight changed only in the body that was deformed. Of course, the decrease in the mass of bodies after an inelastic collision does not occur due to a reduction in the amount of matter, but because of the decrease in the inertial mass, that is, the acceleration coefficient in the second Newton's law ($F = m_i\alpha$). This conclusion follows from the recognition of the active participation of the medium (quantum vacuum) and the law of conservation of momentum.

In 2003 employee of the Russian Academy of Sciences A.V. Rykov modified the experiment of N.A. Kozyrev on inelastic collision of bodies [15]. In the experiment, he included a calorimeter and a lead ball weighing 1 kg, which falls freely into the calorimeter from a height of three meters. It turned out that the amount of energy released during the braking of the lead ball about the steel bottom of the calorimeter is significantly higher than the calculated value, which the ball should have received when free falling from a given height:

$$W = Mgh \quad (6)$$

Where the mass of the ball M = 1kg, the acceleration of gravity g = 9.82 m/s², the height h = 3 m. The value of the released energy for an inelastic collision of the ball on the bottom of the calorimeter should be W = 29.46J. Since lead has a small heat capacity of 140 J / (kg.gradus), the heat produced by the impact of the ball on the bottom of the calorimeter is more effective in raising the temperature of the steel calorimeter with a heat capacity of 400 J / (kg.gradus). On impact, the temperature of the calorimeter with the ball should rise by $\Delta t^0 = 29.46 / 400 = 0.074$, but the temperature increase was $\Delta t^0 = 0.74$, that is, ten times the calculated temperature. Rykov explained the excess of the energy released by the active contribution of the quantum medium (dark energy) to the "calorimeter-ball" system during the course of the irreversible process of deformation of the lead ball upon impact against the bottom of the calorimeter [15].

### 4.2. Dependence of the Inertial Mass of the Body and Violation of the PE on the Speed of Rotation of the Rotors and the Oscillation Frequency of Mechanical Oscillators in the Dmitriev’s Experiments [16]

Unlike the “geometric” concept of A. Einstein's gravity, Professor A.L. Dmitriev adheres to the “field” concept of gravity, which allows one to describe gravitational interactions of bodies similarly to electric and magnetic interactions. In this case, gravitational fields should have properties similar to, but not identical to, the properties of electromagnetic fields. The “field” concept of gravity does not contradict other experimentally grounded approaches in describing the phenomenon of gravitation and inertia, in particular, for example, to certain models involving a quantum vacuum (dark matter). Proceeding from this, Dmitriev in his experiments considered the reaction of gravity applied to the body, on its acceleration α, caused by the action of external non-gravitational forces. Experiments were conducted to estimate the anisotropy of inertial body mass by comparing the period of natural oscillations of a linear mechanical oscillator with the vertical and horizontal orientation of its axis. In his model, describing the influence of the vertical oscillations of the test body on its average weight, Dmitriev introduced the variable in of time the value of the normal acceleration of gravity $g_0$ (t). The calculations show that even for small (hundredths of a percent) of the oscillations of the magnitude of the normal acceleration of the Earth's gravity, the weight of the mechanical oscillator can vary noticeably. The oscillator's weight varies periodically with frequency, and the sign and magnitude of such changes essentially depend on the phase difference Θ of the oscillator oscillations and the acceleration of gravity of the Earth. At high vibrational frequencies of the oscillator, the average weight of the oscillator is monotonously dependent on its oscillation frequency, and the influence of phase Θ is insignificant. Such a decrease in the weight of the oscillator at high frequencies of oscillations is in good agreement with the temperature dependence of the body weight, since the frequency of thermal oscillations of microparticles of solids is very high and lies in the region of hypersound [17]. Dmitriev conducted measurements of the instantaneous value of the free fall acceleration of a closed container with the rotor of a vacuum mechanical gyroscope fixed in it. A mechanical rotor is a system of microparticles that form a solid body moving rapidly along a circular trajectory. The radius of the rotor used in the experiment is R = 140 mm. At frequencies of the oscillator tens of times higher than the natural frequency of the normal gravity acceleration F = 600 Hz, the monotonic frequency dependence of the variation Δg of the average value of the free-fall acceleration is fulfilled, the sign of Δg being directly determined by the phase difference Θ of oscillations, the acceleration of gravity of the Earth and oscillator. Both a significant increase and a decrease in the average gravity acting on the mechanical oscillator from the side of the Earth's alternating gravitational field are possible. Professor AL Dmitriev believes that independent measurements of the high-frequency (the range of hundreds-thousands of Hz) spectra of fluctuations in the acceleration of gravity of the Earth, performed using superconducting gravimeters, will allow us to determine the regimes of matched oscillations of the oscillator, in which changes in its average weight can cause levitation or , on the contrary, a sharp increase in weight. This effect can be the basis for the creation of technical systems to overcome the force of gravity and a new principle of controlling the motion of bodies [18]. Here I would like to note that the same effect today can cause technogenic catastrophes. It was noted experimentally that when the limiting speed of rotation of the rotors of electric motors and turbines is reached, spontaneous acceleration of the disks occurs in a number of cases and, moving vertically along the axis of rotation, they break from the supports and fly out of the device. A similar accident occurred on August 17, 2009 at the Sayano-Shushenskaya hydroelectric power station. The turbine of the second hydroelectric unit suddenly began to rotate at a hypersonic speed, which led to the destruction of the fixing bolts, the destruction of the room and the death of 75 people.

## 5. CONCLUSION

Thus, it can be argued that the “geometric” concept of gravity of A. Einstein requires correction. Based on the “field” concept of gravity, it can be concluded that in a stable stationary state, an active influence on the system from the outside, is negligible, but can become very significant if the system goes into a nonequilibrium state. Moreover, the system becomes non-integrable, weak and strong equivalence principles are violated, and time loses the property of invariance [9]. This determines the limits of applicability of the invariant equations of Einstein's general relativity (GRT). The physical nature of the forces of inertia is different from gravity, although it is related to it. The inertial mass is proportional to the gravitational mass and is due to the interaction of gravitational and electromagnetic forces applied to the body (gravitational induction) [16]. If the interaction of gravitational and electromagnetic forces were absent, then the inertial mass would be zero. This situation is consistent with the principle of Mach, according to which the inertia of matter is determined by the environment. The increase in the accuracy of measurements in experiments conducted today [3], to verify the equivalence principle cannot radically change the picture. It is necessary to change the methodology of experiments.

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