УДК 524.82

# МАССИВНОЕ ГРАВИТАЦИОННОЕ ПОЛЕ В ПЛОСКОМ ПРОСТРАНСТВЕ-ВРЕМЕНИ. III. ГРАВИТАЦИОННАЯ ЗАВИСИМОСТЬ РАДИОАКТИВНОГО РАСПАДА

**М.А. Сердюкова**

*Гомельский государственный университет им. Ф. Скорины*

# A MASSIVE GRAVITATIONAL FIELD IN FLAT SPACETIME. III. GRAVITATIONAL DEPENDENCE OF RADIOACTIVE DECAY

**M.A. Serdyukova**

*F. Scorina Gomel State University*

Показано, что изменение инертной массы нестабильных частиц (и атомных ядер) в скалярном гравитационном поле, возникающее в результате передачи полю части энергии покоя частиц, или, наоборот, при увеличении их энергии покоя за счет аккреции полевой энергии, сопровождается изменением темпов радиоактивного распада. Приложение скалярной теории гравитации к однородной вселенной предсказывает вековое ускорение темпов распада нестабильных ядер и частиц в современную эпоху. В космологическом масштабе времени этот процесс подтверждается наблюдаемым $(1+z)$-растяжением кривых блеска послесвечения сверхновых типа Ia, которое вызвано жестким гамма-излучением от распадающихся нестабильных нуклидов $^{56}$Ni and $^{56}$Co, созданных при взрыве аккрецирующих белых карликов.

***Ключевые слова**: массивная скалярная гравитация, переменная масса, радиоактивный распад.*

It is shown that a change in the inertial mass of unstable particles (and atomic nuclei) in a scalar gravitational field that occurs as a result of the transfer of part of the rest energy of particles to the field, or, conversely, when their rest energy increases due to accretion of field energy, is accompanied by a change in the rate of radioactive decay. The application of the scalar theory of gravity to the homogeneous universe predicts the secular acceleration of the rate of decay of unstable nuclei and particles in the current era. On a cosmological time scale, this process is confirmed by the observed $(1+z)$-stretching of the light curves of supernovae type Ia afterglow caused by the hard gamma-radiation from the decaying unstable $^{56}$Ni and $^{56}$Co nuclides created by the explosion of accreting white dwarfs.

***Keywords**: spinless massive gravity, variable mass, radioactive decay.*

## Introduction

Along with the gravitational shift of the atomic and nuclear spectra of electromagnetic radiation, discussed in a previous article [1], the variability of the rest energy of massive particles in a gravitational field predicted by the scalar special-relativistic theory of gravity leads to another quantum-mechanical effect. This phenomenon manifests itself in the form of a small change in the rate of radioactive decay of unstable nuclei and elementary particles under the influence of local gravitational fields created by the condensed matter of stars, the sun, and the earth.

On the other hand, the application of the proposed scalar gauge-invariant theory of gravity to all the mass in the entire universe predicts the existence of a slowly varying in time collective cosmic gravitational field. The theory predicts also that this background field, which also changes the mass of particles, should affect intranuclear processes, and this effect of gravity should manifest itself, in particular, in the form of secular acceleration or deceleration in large time scales of the rate of radioactive decay. Small deviations in the physics of nuclear processes that gradually took place in the past era, being monotonously accumulating in time, should have significantly increased on a cosmological time scale and should be clearly visible now against the background of well-studied similar nuclear transformations in the current time. The cosmological manifestation of this phenomenon was detected twenty years ago by observing the “dilation of light curves” in the afterglow of the explosion products of accreting white dwarfs as this cosmic event recedes from the observer. It is established by astronomical observations that this afterglow arises at the expense of energy of hard radiation from decaying $\beta$-unstable nuclei $^{56}$Ni and $^{56}$Co created in the fusion process from carbon and oxygen during the explosion, which was identified as a Type Ia supernova.

The use of this type supernovae as cosmic “standard candles” [2]–[5] has shown that the time of their accessible to observation bright glow increases with increasing distance and, consequently, with an increase in the time interval separating our time from these cosmic events of the long past. Specifically, it was measured that the time intervals of the afterglow after SN Ia explosion increase with distance or, in other words, the light curves of a distant supernova with a high cosmological redshift

$z$ are stretched by the factor $(1+z)$ compared to similar curves in neighboring supernovae of this type.

A theoretical description of this phenomenon in the framework of a conformally flat model of the universe with a background gravitational field with cyclic dynamics was proposed in my earlier publication [6]. Later, when we turn to cosmological problems without going beyond the framework of the accepted gauge-invariant model of gravity, we will also return to a more detailed discussion of the problem of cosmological acceleration at present epoch of the rates of radioactive decay of both rapidly decaying and long-lived isotopes under the influence of a background gravitational field.

**1 The effect of gravitation on the rate of radioactive decay**

If the quantum-mechanical system such as atom, atomic nucleus, or other real massive structural object is placed in the external gravitational field, simultaneously with the gravitational change of its rest energy [1], [7], [8]

$$\mathcal{E} = c^2 m e^{\Phi/c^2}, \qquad (1.1)$$

the change in the natural width $\Delta\mathcal{E}$ of its energy levels should also occur when the gravitational potential $\Phi$ changes. This change must be, of course, in the same proportion as in (1.1), that is, with the same Nordström's energy content factor

$$\phi^2 = e^{\Phi/c^2}.$$

Therefore from the law (1.1) of mass–energy transformation in a gravitational field and the quantum mechanical uncertainty relation between the width $\Delta\mathcal{E}$ of energy levels and the lifetime $\Delta\tau$ of excited states,

$$\Delta\tau \cdot \Delta E \sim \hbar,$$

it follows that the lifetime of a system in bounded state depends on the potential in such a way that

$$\Delta\tau \cdot e^{\Phi/c^2} = const. \qquad (1.2)$$

Noting the obvious fact that the lifetime $\Delta\tau$ with respect to the radioactive decay of a particular type of radionuclide (or other unstable particles, such as, for example, neutrons) is proportional to their half-life $T^{(1/2)}$, we conclude from the connection (1.2), that the half-life of unstable particles in a gravitational field varies with the field potential $\Phi$ according to the relation

$$T^{(1/2)}(\Phi) = T_0^{(1/2)} e^{-\Phi/c^2}. \qquad (1.3)$$

Obviously, the value of the half-life of the considered unstable particle locater in the space region, where for the gravitational potential we choose the gauge condition $\Phi = 0$, should be taken in (1.3) as the constant $T_0^{(1/2)}$.

So, taking into account the above arguments, the usual law of radioactive decay

$$N(t) = N_0 e^{-\lambda t},$$

where

$$\lambda = \frac{\ln 2}{T^{(1/2)}},$$

in the presence of a static (or stationary) gravitational field, whose potential is constant in time, should be rewritten in the form:

$$N_\Phi(t) = N_0 \exp\left(-\frac{\ln 2 \cdot e^{\Phi/c^2}}{T_0^{(1/2)}} t\right). \qquad (1.4)$$

We will be interested next in the ratio of the numbers $N_A(t)$ and $N_B(t)$ of unstable particles that survived at time $t$ in every of two initially identical their amounts, which were located in different regions of field, $A$ and $B$, with different constant values $\Phi_A$ and $\Phi_B$ of potential. From (1.4) it is easy to see that

$$\frac{N_A(t)}{N_B(t)} = \exp\left[\frac{\ln 2}{T_0^{(1/2)}}\left(e^{\Phi_B/c^2} - e^{\Phi_A/c^2}\right)t\right].$$

For a weak field in the linear approximation with respect to the small parameter $\Phi/c^2$, from this we obtain

$$\frac{N_A(t)}{N_B(t)} \approx \exp\left(-\frac{\ln 2}{T_0^{(1/2)}} \cdot \frac{\Phi_{AB}}{c^2} t\right).$$

where $\Phi_{AB} = \Phi_A - \Phi_B$. If the decay time $t$ is comparable to the half-life $T_0^{(1/2)}$, which, of course, is implied, the last formula is further simplified:

$$\frac{N_A(t)}{N_B(t)} \approx 1 - \frac{\ln 2}{T_0^{(1/2)}} \cdot \frac{\Phi_{AB}}{c^2} t. \qquad (1.5)$$

**2 Gravitational variability of the decay rate of $^{238}$U on the Earth**

Now, on the basis of this formula we estimate the order of magnitude of the ratio of non-decayed fractions for long-lived $^{238}$U isotopes that were located in the center of the Earth and on its surface for the entire time after completion of its formation as a planet. For this purpose, we use the well-known solution of the Poisson equation for the potential of the Newtonian theory of gravitation (see, for example, [9])

$$\Phi(r) = \begin{cases} \dfrac{G_N M}{2R}\left(\dfrac{r^2}{R^2} - 3\right) & \text{for } r \le R, \\[2ex] -\dfrac{G_N M}{r} & \text{for } r \ge R, \end{cases} \qquad (2.1)$$

which determines the field of a massive homogeneous spherical body of mass $M$ and radius $R$ both inside it and in the entire surrounding space under the gauge condition $\Phi = 0$ at infinity. Assuming next $M = M_\oplus$, $R = R_\oplus$, and bearing in mind that the acceleration of gravity on the surface of the planet

$$g = \frac{G_N M_\oplus}{R_\oplus^2},$$

we find from formula (2.1) the expressions for the potential in center of the Earth $(r = 0)$:

$$\Phi_A = \Phi_{\text{center}} = -\frac{3}{2} g R_\oplus,$$

and on its surface $(r = R)$:

$$\Phi_B = \Phi_{\text{surface}} = -g R_\oplus .$$

From this it follows

$$\Delta\Phi_{AB} = -\frac{1}{2} g R_\oplus .$$

Now from (1.5) we find the final formula for calculating the relative content of undecayed unstable isotopes of a certain kind in similar geological rocks in the center and on the surface of the Earth (or another planet) after a long period of time $t$ elapsed after their formation:

$$\frac{N_{\text{center}}(t)}{N_{\text{surface}}(t)} = 1 + \frac{\ln 2 R_\oplus g t}{2c^2 T_0^{(1/2)}}.$$

In carrying out a numerical calculation on the example of uranium-238 isotopes, which half-life is equal $T^{(1/2)} = 4.468 \cdot 10^9$ years [10], we note additionally that the approximate age of the Earth is estimated at 4.5 billion years, and remember also that $R_\oplus \simeq 6.371 \times 10^6\,\text{m}$, $g = 9.8\,\text{ms}^{-2}$, and $c \simeq 10^8\,\text{ms}^{-1}$. As a result, we have

$$\frac{N_{\text{center}}(t)}{N_{\text{surface}}(t)} \approx 1 + 2.4 \times 10^{-10}.$$

As calculations show, due to the extreme smallness of the dimensionless relative magnitude of the gravitational field on the Earth's surface,

$$\frac{\Phi}{c^2} = \frac{R_\oplus g_{\text{surface}}}{c^2} \approx 7 \cdot 10^{-10},$$

the ratio of the concentration of long-lived isotopes on its surface and in the center during the Earth's existence can very small differs from unity.

But if radioactive decay had to be used as a clockwork, then the deviation from unity calculated in (1.5) is two orders of magnitude greater than that which allowed Richard Feynman in [15] to state that "the center of the earth should be a day or two younger than the surface".

## REFERENCES


1. *Serdyukova*, *M.A*. A Massive Gravitational Field in Flat Spacetime. II. Conservation Laws and Gravitational Variability of the Inertial Mass / M.A. Serdyukova, A.N. Serdyukov // Problems of Physics, Mathematics and Technics. – 2019. – № 3 (40). – P. 33–39.

2. *Time dilation in the light curve of the distant Type* Ia *Supernova* SN 1995K / B. Leibundgut [et al.] // Astrophys. J. Lett. – 1966. – № 466. – L21–L44.

3. *Perlmutter*, *S*. Discovery of a Supernova explosion at half the age of the universe / S. Perlmutter // Nature. – 1988. – № 391. – P. 51–54.

4. *Timescale stretch parameterization of Type* Ia *Supernova* B-*band light curves* / G. Goldhaber [et al.] // Astrophys. J. – 2001. – № 558. – P. 359–368.

5. *Time dilation in Type* Ia *Supernova spectra at high redshift* / S. Blondin [et al.] // Astrophys. J. – 2008. – Vol. 682. – P. 724–736.

6. *Serdyukova*, *M.A*. The Law of Radioaktive decay in a cyclic non-expanding universe / M.A. Serdyukova // Topical Issues of Physics and Technology. Materials of the V Republican scientific conference of students, undergraduates and graduate students (Gomel, April 21, 2016). – Part 2. – Gomel: F. Skorina Gomel State University, 2016. – P. 80–83.

7. *Nordström*, *G*. Relativitäts prinzip und Gravitation / G. Nordström // Phys. Z. – 1912. – № 13. – S. 1126 –1129.

8. *Nordström*, *G*. Träge und schwere Masse in der Relavitätsmechanik / G. Nordström // Ann. Phys. (Leipzig). – 1913. – № 40. – S. 856–878.

9. *Serdyukov*, *A.N*. Gauge Theory of Scalar gravitational Field / A.N. Serdyukov. – Gomel: Gomel State Universe, 2005. – 257 p.

10. *The NUBASE evaluation of nuclear and decay properties* / G. Audi, O. Bersillon, J. Blachot, A.H. Wapstra // Nuclear Physics. A. – 2003. – Vol. 729. – P. 3–128.

11. *Serdyukova*, *M.A*. A Massive Gravitational Field in Flat Spacetime. I. Gauge Invariance and Field Equations / M.A. Serdyukova, A.N. Serdyukov // Problems of Physics, Mathematics and Technics. – 2019. – № 2 (39). – P. 45–53.

12. *Gamov*, *G*. Expanding Universe and the origin of elements / G. Gamov // Phys. Rev. – 1946. – Vol. 70. – P. 572–573.

13. *Alpher*, *R.A*. The origin of the chemical Elements / R.A. Alpher, H. Bethe, G. Gamov // Phys. Rev. – 1948. – Vol. 73. – P. 803–804.

14. *Alpher*, *R.A*. A neutron-capture theory of the formation and relative abundance of the elements / R.A. Alpher // Phys. Rev. – 1948. – Vol. 74. P. 1577–1589.

15. *Feynman Lectures on Gravitation* / R.P. Feynman [et al.]. – Reading, Pennsylvania: Addison-Wesley, 1995. – 232 p.


*Поступила в редакцию* 03.06.19.