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Research on Vacuum Dynamics Theory and Physical Mechanism of Gravitational Acceleration

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Abstract

Based on the principle of constant speed of light and the principle of minimum energy, this paper innovatively proposes the principle of relative change of light speed and constructs a theoretical system of vacuum dynamics. By revealing the dynamic mechanism of spontaneous force caused by light speed gradient, this theory provides an innovative dynamic interpretation framework for gravitational interaction and dark energy phenomena, making up for the deficiency in the discussion of dynamic mechanism in general relativity. The core research results are as follows: 1. **Principle of spacetime-light speed covariance**: It reveals the physical law that the ratio of spacetime change to relative change of light speed must be consistent. 2. **Dynamic mechanism of vacuum light speed gradient**: It is proposed that the light speed gradient can cause spontaneous motion of objects, and its acceleration is the negative gradient of the square of light speed: $g_m = -\nabla c^2$. 3. The gravitational acceleration derived from the vacuum dynamics theory is completely equivalent to that from general relativity. This thus supplements the dynamic mechanism for the geometric interpretation that "spacetime curvature is gravity". 4. A gradient distribution model of light speed in the universe with higher speed inside and lower speed outside is proposed: The essence of cosmic expansion is the spontaneous movement of celestial bodies towards regions with lower light speed (i.e., lower energy), and dark energy is essentially the internal energy released and converted into kinetic energy by celestial bodies in this process.

Keywords: vacuum dynamics; speed of light gradient; gravitational mechanism; spacetime-light speed covariance principle; principle of relative change of light speed

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1. Introduction

1.1. Research Background and Problem Formulation

The principle of constant speed of light is the core of the theory of relativity. However, experiments such as radar echo delay [1] and gravitational lensing [2] have shown that light experiences additional delays and path bending when propagating near massive celestial bodies, indicating that the speed of light undergoes relative changes in non-inertial environments such as strong gravitational fields. This contradiction necessitates the construction of a theoretical framework that is compatible with both the invariance and relative variability of the speed of light, aiming to systematically explain the laws of light speed changes in different spatial environments and their impact on material motion.

1.2. Research Objectives and Theoretical Innovations

This study proposes the principle of relative change of light speed based on the principle of constant speed of light, and constructs a theoretical system of vacuum dynamics. The innovation lies in the first revelation of the dynamic mechanism by which light speed gradients induce spontaneous motion of objects, providing a new explanatory framework for gravity and dark energy. Specific objectives include: establishing the covariant relationship between spacetime quantities and the speed of light; offering a non-geometric dynamic explanation for gravitational phenomena; and

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proposing a dynamic model of dark energy to explain the physical essence of the accelerated expansion of the universe.

2. Core Points of Vacuum Dynamics Theory

2.1. Principle of Spacetime Covariance

Consider two vacuum space regions, A and B. Based on the principle of constant speed of light, the measured speed of light in both local regions A and B is the constant speed of light c , i.e.:

$$c = \frac{\Delta s_a}{\Delta t_a} = \frac{\Delta s_b}{\Delta t_b} \qquad (2\text{-}1)$$

In the above equation, Δt_a and Δt_b are the times required for light to propagate through Δs_a and Δs_b respectively. This equation intuitively reflects the invariance of the speed of light in different local spaces.

Transforming formula (2-1) into the proportional relationship between space and time:

$$k = \frac{\Delta s_b}{\Delta s_a} = \frac{\Delta t_b}{\Delta t_a} \qquad (2\text{-}2)$$

The above formula shows that the relative changes in space and time must occur synergistically in an equal proportion. This conclusion, derived from the principle of constancy of the speed of light, is an inevitable result and thus admits of no exceptions. This regularity is referred to as the "principle of spacetime covariance".

2.2. Principle of Relative Change of Light Speed [3,4]

When spaces A and B undergo relative changes, the relative speed of light between the two spaces will change accordingly. According to the principle of constancy of the speed of light, the speed of light within each of spaces A and B is 300,000 kilometers per second. However, if space B contracts by 50% relative to space A (meaning 300,000 kilometers in space B is equivalent to only 150,000 kilometers in space A), then from the perspective of space A, the speed of light in space B will be 150,000 kilometers per second, which is only 50% of the speed of light in space A. It can thus be seen that if the speed of light in other spacetimes is measured with the spacetime of a certain space as the reference, the result may differ from the speed of light in the local space. This regularity is known as the "principle of relative change of the speed of light". This principle is based on the principle of constancy of the speed of light, and there is no contradiction between the two; they only show differences due to different perspectives of observing the speed of light.

The proportional relationship between spatial changes and changes in the speed of light can be expressed as:

$$k = \frac{s_b}{s_a} = \frac{c_b}{c_a} \qquad (2\text{-}3)$$

In flat spacetime, the speed of light remains relatively constant; whereas in curved spacetime, the speed of light exhibits relative changes. The phenomenon of radar echo delay is a typical example of the relative change in the speed of light when light travels through different spacetime environments.

2.3. Principle of Spacetime-Light Speed Covariance

Combining equations (2-2) and (2-3) yields:

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$$k = \frac{\Delta s_b}{\Delta s_a} = \frac{\Delta t_b}{\Delta t_a} = \frac{c_b}{c_a} \qquad (2\text{-}4)$$

The above formula reveals the physical law of unified covariance among time, space, and the speed of light, which is referred to as the "Space-Time-Speed of Light Covariance Principle". This principle is a concrete manifestation of the principle of constancy of the speed of light under the condition of varying spacetime: only when the speed of light changes in proportion to time and space can the consistency of the speed of light at any local point be ensured. Time and space can serve as scales for measuring the speed of light but cannot alter the speed of light itself; meanwhile, there are deeper physical causes that determine the synchronous changes of time, space, and the speed of light, which are preliminarily discussed in Section 3.2.2 of this paper.

2.4. Energy Difference Caused by Light Speed Difference

2.4.1. Redshift Caused by Light Speed Difference

In spaces with relatively unequal light speeds, according to the principle of spacetime-light speed covariance, frequencies also differ relatively, as shown in the equation:

$$f_a = \frac{c_b}{c_a} f_b \qquad (2\text{-}5)$$

It can be seen from the above equation that when light from a low-light-speed space enters a high-light-speed space, its frequency undergoes a redshift phenomenon, and the photon energy also decreases accordingly.

2.4.2. Internal Energy Difference Caused by Light Speed Difference

According to the mass-energy relationship ($E_0 = m_0c^2$), the speed of light is a key parameter determining the internal energy of an object, directly influencing its intrinsic energy state. For the same object with a rest mass of m_0, its internal energy is proportional to the square of the speed of light in the space where it is located: when the object is in a space with a higher speed of light, its internal energy increases accordingly; conversely, when it is in a space with a lower speed of light, its internal energy decreases.

This characteristic reveals the quantitative correlation between the difference in the speed of light and the difference in internal energy: the relative change in the speed of light in space is converted into the relative difference in the internal energy of an object through the mass-energy relationship. Such an internal energy difference caused by the difference in the speed of light may become a potential mechanism driving energy exchange or state changes of matter in different spacetime environments, providing important clues for understanding the in-depth connection between spacetime properties and material energy.

2.4.3. Division of Energy Spaces

From the above analysis, it is known that the energy of both photons and objects varies relatively with the speed of light. From the perspective of energy, vacuum space is divided into three categories:

- High-energy space: a space with a relatively high speed of light ($\nabla c=0$).
- Low-energy space: a space with a relatively low speed of light ($\nabla c=0$).
- Variable-energy space: a space where the speed of light changes continuously ($\nabla c\neq0$).

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2.5. Spontaneous Motion of Objects in Vacuum

2.5.1. Motive and Energy Source of Spontaneous Motion

In a closed variable-energy system, even if an object is not subjected to any external force, it will spontaneously move toward the direction of a low-energy state. Behind this spontaneous motion lies one of the most general laws of material motion, namely the principle of minimum energy [5–7]. This principle states that any object or system, under ideal conditions without external interference, will spontaneously tend to a state of minimum energy. Specifically, this is manifested as the system continuously developing toward the lowest energy state through energy exchange, transformation, or transfer.

It is worth noting that this law has wide applicability. From a macroscopic perspective, celestial processes such as stellar evolution and galaxy movement follow this law; from a microscopic perspective, physical and chemical behaviors such as atomic energy level transitions and molecular conformation adjustments are also governed by it. It can thus be concluded that the movement of an object toward the low-energy state in a variable-energy space is a specific manifestation of the intrinsic property of the object itself to pursue the lowest energy state.

Since in this spontaneous motion process, neither external forces do work on the object nor the object does work on the outside, the change in the total energy of the object ΔE should be zero. Therefore:

$$\Delta E = \Delta Ei + \Delta Ev = 0 \qquad (2\text{-}6)$$

Thus, we can derive:

$$\Delta Ev = -\Delta Ei \qquad (2\text{-}7)$$

where ΔEi is the change in internal energy, and ΔEv is the change in kinetic energy. It can be seen from the above equation that the increased kinetic energy of the object originates from its internal energy. The law of conservation of energy is always satisfied during this spontaneous motion process.

Through the above analysis, we have clarified the motivation for the spontaneous movement of objects in a variable-energy space and the source of their kinetic energy.

2.5.2. Spontaneous Force $\boldsymbol{F}_{\mathrm{m}}$ of Objects

When an object spontaneously accelerates toward the low-energy state, it is equivalent to being acted upon by a force. Since this force arises from the spontaneous tendency of the object to move toward the low-energy state rather than an external force, this equivalent force is defined as the spontaneous force $\boldsymbol{F}_{\mathrm{m}}$ originating from the interior of the object. It can also be called the "fifth force".

Assume that the work ΔA done by the object under the action of the spontaneous force $\boldsymbol{F}_{\mathrm{m}}$ is equal to the increment of the object's kinetic energy ΔE_{v}, i.e.:

$$\Delta A = F_{\mathrm{m}} \cdot \Delta s = \Delta E_{\mathrm{v}} = -\Delta E_{\mathrm{i}} \qquad (2\text{-}8)$$

Thus, we can derive:

$$\boldsymbol{F}_{\mathrm{m}} = -\frac{dE_{\mathrm{i}}}{ds}\vec{S} \qquad (2\text{-}9)$$

Substituting $E_{\mathrm{i}} = mc^2$ into the above equation, the mass can be regarded as a constant under low-speed conditions.

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Then:

$$\boldsymbol{F}_{\mathrm{m}} = -m\frac{d(c^2)}{ds}\vec{s}, \qquad (2\text{-}10)$$

It can be seen from equations (2-9) and (2-10) that the generation of the spontaneous force $\boldsymbol{F}_{\mathrm{m}}$ involves two factors: the internal factor is the rate of change of the object's internal energy with respect to space, and the environmental factor is the rate of change of the square of the speed of light with respect to space—which is precisely the environmental factor that causes the spatial variation of the object's internal energy. It is worth noting that even if the object is in a macroscopically stationary state, as long as the aforementioned environmental factor exists, a spontaneous force $\boldsymbol{F}_{\mathrm{m}}$ pointing in the direction of decreasing internal energy (i.e., decreasing speed of light) will be generated. This mechanical phenomenon is consistent with the phenomenon that a stationary object in a gravitational field is always subject to gravitational force.

2.5.3. Acceleration Related to Spontaneous Force

According to Newton's second law ($\boldsymbol{F} = \boldsymbol{ma}$) , let $\boldsymbol{g_m}$ be the acceleration generated by the spontaneous force:

$$\boldsymbol{g_m} = \frac{\boldsymbol{F_m}}{\boldsymbol{m}} \qquad (2\text{-}11)$$

Substituting equation (2-10) into the above equation, the expression for acceleration is obtained:

$$\boldsymbol{g_m} = -\frac{\boldsymbol{d(c^2)}}{\boldsymbol{ds}}\vec{s} \qquad (2\text{-}12)$$

Extending to the three-dimensional space case, suppose the speed of light c is a scalar function of the spatial coordinates (x, y, z) (i.e., forming a scalar field (c = c(x, y, z) , and the negative gradient of the square of this scalar field is an acceleration vector field $\boldsymbol{g_m}$:

$$\boldsymbol{g_m} = -\boldsymbol{\nabla c}^2 \qquad (2\text{-}13)$$

From the above discussion, it is known that the speed of light c forms a scalar field in space. The negative gradient of the square of this light speed field generates an acceleration vector field consisting of $\boldsymbol{g_m}$. It can be seen from equation (2-13) that the acceleration acquired by the object is independent of its own mass. This characteristic is completely consistent with the property that the acceleration of an object in free fall in a gravitational field is independent of its own mass.

2.6. Important Conclusions of Vacuum Dynamics Theory and Its Connection with Relativity

2.6.1 In vacuum space, as long as there is a light speed gradient ($\boldsymbol{\nabla c} \neq \boldsymbol{0}$), an object will spontaneously accelerate toward the direction of lower light speed. This motion requires no external force or fulcrum, and the increased kinetic energy of the object comes from the reduced (saved) internal energy of the object. This discovery provides theoretical support for non-propellant engine technology and a unified explanatory framework for gravitational phenomena and dark energy phenomena.

2.6.2 The principle of spacetime-light speed covariance has important physical significance. It advances the correlation between spacetime, light speed, and material motion from "geometric description" to "dynamic mechanism": it not only retains the experimental basis of the theory of relativity (constant speed of light, relativity of spacetime) but also reveals the intrinsic unity of spacetime and light speed through the logic of "coordinated changes", providing a theoretical basis for making up for the deficiency of general relativity in dynamic mechanisms.

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3. Interpretation of Universal Gravitation by Vacuum Dynamics Theory

3.1. Gravitational Acceleration $\boldsymbol{g}$ *and Vacuum Dynamics Hypothesis*

3.1.1. Classical Gravitational Basis

The expression of gravitational acceleration derived from the law of universal gravitation is:

$$\boldsymbol{g} = -G\frac{M}{r^2}\vec{\boldsymbol{r}} \qquad (3\text{-}1)$$

where $\boldsymbol{g}$ is the gravitational acceleration, G is the gravitational constant, M is the mass of the celestial body, and r is the distance from the center of the celestial body to the point in question.

3.1.2. Equivalence Hypothesis and Derivation

Assume that the acceleration g_m caused by the light speed gradient is proportional to the gravitational acceleration $\boldsymbol{g}$:

$$g \propto g_m \qquad (3\text{-}2)$$

After introducing the fitting coefficient j:

$$g = jg_m \qquad (3\text{-}3)$$

By comparing with the experimental results of general relativity, it is determined that j = 1/2 . Substituting equations (2-12) and (3-1) into the above equation, the vector equation is obtained, which is further simplified to a scalar equation:

$$-j\frac{dc^2(r)}{dr}\vec{\boldsymbol{r}} = -\frac{GM}{r^2}\vec{\boldsymbol{r}} \qquad (3\text{-}4)$$

$$\frac{1}{2}\frac{dc^2(r)}{dr} = \frac{GM}{r^2} \qquad (3\text{-}5)$$

3.1.3. Finding the Radial Distribution Function c(r) of the Light Speed Field

The radial distribution function c(r) of the light speed field can be derived from equation (3-5). Integrating both sides of equation (3-5) gives:

$$c^2(r) = \int\frac{2GM}{r^2}dr = D - \frac{2GM}{r} \qquad (3\text{-}6)$$

Boundary condition: When $r \to \infty$, the speed of light is the intrinsic speed of light c_0 at infinity, so $D = c_0^2 = c^2$. Thus, the light speed distribution function is obtained:

$$c^2(r) = c^2 - \frac{2GM}{r} = c^2\left(1 - \frac{2GM}{c^2\,r}\right) \qquad (3\text{-}7)$$

Taking the square root, we get:

$$c(r) = c\sqrt{1 - \frac{2GM}{c^2r}} \qquad (3\text{-}8)$$

The above equation is the spatial distribution function of the speed of light determined by a spherically symmetric object. The measured speed of light at any point on the radial line is c, and the

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speed of light c(r) is the relative speed relative to the point c_0, which conforms to the principle of relative change of light speed.

It can be seen from formula (3-8) that when the radial distance r decreases to a certain critical value, the local speed of light c(r) approaches zero. According to the space-time-light speed covariance principle, the local time flow rate and spatial interval at this point will also approach zero. Setting c(r) = 0 and solving it gives: $r = 2GM/c^2$. The expression of this critical radius is completely consistent with the definition of the Schwarzschild radius Rs .

3.2. Analysis of the Light Speed Field Equation c(r)

3.2.1. Gravitational Effect Generated by the Light Speed Field

The light speed radial distribution function describes the continuous distribution of light speed around a spherically symmetric gravitational source, which is lower in the inner part and higher in the outer part, forming a variable energy space. Objects spontaneously accelerate towards the low-energy region (the center of the gravitational source), with the acceleration $g_m = -\nabla c(r)^2$, and the spontaneous force $F_m = -m\nabla c(r)^2$. The increment of kinetic energy comes from the reduction of internal energy, and the spontaneous force at this time is what we call gravity.

The gravitational source establishes a light speed scalar field by changing the light speed distribution c(r), and its gradient ∇c^2 constitutes a vector field (gravitational field) characterized by the gravitational acceleration g_m. The acceleration of an object is independent of its own mass, which is consistent with the characteristics of the traditional gravitational field. Moreover, there is no direct attractive force between objects, and gravity is indirectly realized through the change of the light speed field distribution by the gravitational source. This is the physical mechanism of the gravitational effect.

3.2.2. Covariant Law Between the Light Speed Distribution Function c(r) and Space-Time Scales

Mathematical Derivation of the Covariance Between the Light Speed Field and Space-Time

From the light speed field distribution function (Equation 3-8), the relative variation factor of light speed can be obtained:

$$k = \frac{c(r)}{c} = \sqrt{1 - \frac{2GM}{c^2 r}} \qquad (3\text{-}9)$$

Based on the space-time - light speed covariance principle, the relative change of space-time scales and the light speed variation factor satisfy the same proportional relationship:

$$k = \frac{\Delta s(r)}{\Delta s} = \frac{\Delta t(r)}{\Delta t} = \frac{c(r)}{c} = \sqrt{1 - \frac{2GM}{c^2 r}} \qquad (3\text{-}10)$$

where:

- Δs, Δt, and c are the space interval, time interval, and intrinsic light speed far away from the gravitational source (approximately flat space-time), respectively;
- Δs(r), Δt(r), and c(r) are the space interval, time interval, and local light speed at a distance r from the center of the gravitational source, respectively.

The Influence of Gravitational Sources on Spacetime

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From the above covariant relationship (3-10), three fundamental equations describing the influence of gravitational sources on spacetime can be derived, as follows:

1. **Time Dilation Formula**

$$\Delta t(r) = \Delta t\sqrt{1 - \frac{2GM}{c^2 r}} \qquad (3\text{-}11)$$

The above equation indicates that, under the action of the gravitational source M , the time progression $\Delta t(r)$ at any point on the radial line is dilated relative to the proper time progression Δt .

2. Spatial Contraction Formula

$$\Delta s(r) = \Delta s\sqrt{1 - \frac{2GM}{c^2 r}} \qquad (3\text{-}12)$$

This equation reflects that, under the influence of the gravitational source M , the spatial interval $\Delta s(r)$ at any point on the radial line undergoes a contraction effect relative to the proper spatial interval Δs.

3. Inverse Operation of Spatial Contraction

$$\Delta s(r) = \Delta s\sqrt{1 - \frac{2GM}{c^2 r}} \qquad (3\text{-}12)$$

This is the inverse transformation of the spatial contraction formula (3-12), whose physical meaning is as follows: $\Delta s(r)$ denotes the coordinate scale observed under the influence of the gravitational source, while Δs represents the proper scale in the absence of gravitational source influence.

All three equations above can be derived from the Schwarzschild metric and have been fully verified by numerous experimental results [8–13].

3.2.3. Physical Reality of the Light Speed Distribution Function c(r)

The vacuum dynamics theory derives three core equations describing the effects of a spherically symmetric gravitational source (mass M) on time, space intervals, and the spatial distribution of light speed:

Light speed distribution function: $c(r) = c\sqrt{1 - 2GM/(c^2 r)}$ (3-8)
Variation of time interval: $\Delta t(r) = \Delta t\sqrt{(1 - 2GM/(c^2 r))}$ (3-11)
Variation of space interval: $\Delta s(r) = \Delta s\sqrt{1 - 2GM/(c^2 r)}$ (3-12)

These equations can also be derived from the Schwarzschild metric in general relativity. It can be seen from the above equations that the mass M of the gravitational source is the fundamental cause of the variations in time, space intervals, and light speed in space. There is only a consistency in the variation ratio ($k = \sqrt{1 - 2GM/(c^2 r)}$) among time, space, and light speed, without any physically significant causal relationship.

The light speed distribution function c(r) indicates that light speed gradually decreases from the region far away from the gravitational source to the direction close to the gravitational source. As can be seen from the above formulas, the proportional coefficients of the variations of time, space, and light speed with radial distance r are the same. It is this completely synchronized proportional change that ensures that the actually measured light speed at any point r on the radial path is always constant at c. However, when examining the propagation speed of light at different points on the radial direction from a fixed reference frame (such as using the light speed c at infinity and the space-time scales Δs and Δt as the unified standards), light speed will show continuous relative changes. This means that we must recognize both the invariance of local light speed and the objective fact that there are relative changes in light speed in a fixed reference frame.

The following three high-precision experiments directly prove the physical reality of the existence of a variable light speed space:

1. Gravitational redshift phenomenon: $f_2/f_1 = c(r_1)/c(r_2)$. When $r_2 > r_1$ (light is far away from the gravitational source), $f_2 < f_1$, that is, redshift occurs.

Experimental verification[14,15]: The 1959 Pound-Rebka experiment verified the existence of gravitational redshift by measuring the frequency shift of γ-rays in the Earth's gravitational field, with an error of only 1% of the theoretical value.

2. Light deflection phenomenon: The light speed gradient $\nabla c(r)$ forms an equivalent refractive index $n(r) = c/c(r)$, causing light to bend toward the low light speed region.

Experimental verification [16,17]: The deflection of starlight at the edge of the Sun is 1.75 arcseconds (accuracy > 99.9%).

3. Light delay phenomenon: The time for light to propagate from r_1 to r_2 is $t = \int_{r_1}^{r_2} \frac{dr}{c(r)}$t . Under the weak field approximation, the delay time is $\Delta t \approx 2GM/c^3 \ln((4r_1r_2)/R^2)$.

Experimental verification [18,19]: In the radar echo delay experiment in the 1960s, the delay time of radar signals emitted from the Earth and reflected by Venus under the action of the Sun's gravitational field was consistent with the theoretical prediction, with an error of less than 0.5%.

All the aforementioned phenomena can be uniquely predicted by the light speed distribution function. If we assume that the speed of light is constant ($c(r) \equiv c$), the gravitational redshift phenomenon will disappear, the deflection angle of light will be halved, and the time delay of light will be zero, which is completely inconsistent with the actual experimental results. This fully indicates that the variable light speed space is an objective physical structure excited by gravitational sources, and these experiments also provide strong empirical support for the vacuum dynamics theory.

3.2.4 To sum up, the vacuum dynamics theory reveals that the light speed gradient is the physical mechanism generating gravity. This core cognition makes gravity no longer limited to an abstract mathematical model, but originates from an observable and measurable physical quantity — the light speed field gradient (∇c^2). In terms of the physical mechanism generating gravitational phenomena, there is no direct attractive force between objects.

The value of this gravitational theory not only lies in providing a new physical interpretation for gravitational phenomena, but also in building an important theoretical bridge for the unification of the electromagnetic field and the gravitational field, as well as for the interdisciplinary integration with other physical disciplines.

4. Connection and Complementarity with General Relativity

4.1. The Physical Essence of the Consistency of Space-Time Views Between the Two Theories

Through its light speed field distribution equation $c(r)$, the vacuum dynamics theory deduces the space-time transformation relations (3-11) and (3-13), which are completely equivalent in mathematical form to the corresponding space-time transformation formulas of general relativity. Taking the Schwarzschild metric as an example, the expression of its time component g_{00} is:

$$g_{00} = -\left(1 - \frac{2GM}{c^2 r}\right) \qquad (4-1)$$

Comparing with the light speed distribution function of the vacuum dynamics theory:

$$c^2(r) = c^2\left(1 - \frac{2GM}{c^2 r}\right) \qquad (4-2)$$

It can be found that they satisfy a concise corresponding relationship:

$$c^2(r) = -c^2 g_{00} \qquad (4-3)$$

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This formula directly relates the core physical quantity of the vacuum dynamics theory, the light speed distribution function $c^2(r)$, to the core geometric quantity of general relativity, the time component of the space-time metric g_{00}, revealing the inherent consistency in the mathematical expressions of the two theories.

From the perspective of physical mechanism, the vacuum dynamics theory introduces the space-time-light speed covariance principle: the spatial scale, time passing rate and light speed change at any two points in space must satisfy the physical constraint that they occur synchronously and have the same change ratio, i.e., $\Delta s(r)/\Delta s = \Delta t(r)/\Delta t = c(r)/c$. This principle constitutes the underlying logic for the unification of the space-time views of the two theories.

4.2. Supplementing the Dynamical Mechanism for General Relativity

4.2.1. Deficiencies in the Dynamical Mechanism of General Relativity

General relativity interprets gravity as a geometric effect of spacetime curvature. Although it can accurately predict the motion of objects, its dynamical mechanism has two fundamental deficiencies:

- Lack of dynamical mechanism: It only describes the phenomenological correlation that "spacetime curvature causes objects to move along geodesics", but does not reveal how spacetime curvature is transformed into the physical force that drives objects to accelerate, nor the dynamical process of interaction between curved spacetime and objects.
- Unclear energy source: It cannot explain the source of kinetic energy for objects accelerating in curved spacetime, nor does it clarify the conservation mechanism between gravitational field energy and the kinetic energy of object motion.

4.2.2. Supplement to the Dynamical Mechanism of General Relativity

The vacuum dynamics theory points out that the light speed gradient is the fundamental source of the dynamical mechanism of gravitational phenomena, and this theory can serve as the best supplement to the dynamical mechanism of general relativity. Studies have shown that the gravitational acceleration derived from the vacuum dynamics theory is completely equivalent to that derived from general relativity, as proved below:

Given the equation:

$$c^2(r) = -c^2 g_{00} \tag{4-4}$$

Taking the gradient of both sides of the above equation and rearranging, we get:

$$\frac{1}{2}\nabla c^2(r) = -\frac{1}{2}c^2\nabla g_{00} \tag{4-5}$$

It can be seen from the above equation that the gravitational accelerations derived from the vacuum dynamics theory and general relativity are completely equal in magnitude. This means that the intrinsic dynamical mechanism of the gravitational acceleration calculated through spacetime curvature actually originates from the effect of the light speed gradient. Therefore, the statement that "spacetime curvature generates gravity" should be regarded as a correlational description rather than a causal relationship in the physical sense. Precisely because of this, spacetime curvature cannot explain the reason for the accelerated motion of objects from the perspective of mechanical mechanisms, while the vacuum dynamics theory just provides a perfect supplement to general relativity at the level of dynamical mechanisms.

5. The Origin of Dark Energy [20]

The essence of the universe's accelerated expansion lies in the outward accelerated diffusion of celestial bodies, a phenomenon that appears to be acted upon by a certain "antigravity". According to the theory of vacuum dynamics, gravity originates from the gradient of the speed of light, while the formation condition for the so-called "antigravity" is as follows: there exists an inward-outward gradient of the speed of light in the universe, causing celestial bodies to spontaneously accelerate toward regions with lower light speed (i.e., the outer regions of the universe). The source of their kinetic energy is precisely the internal energy released and converted into kinetic energy when celestial bodies move toward space with lower light speed—this internal energy converted into kinetic energy is what we refer to as dark energy[20]. The speed of light in the universe exhibits a gradient distribution characteristic of "higher at the center and lower at the edges", a conclusion supported by astronomical observations.

- **Light Delay Phenomenon**: Multiple astronomical observation results show that the time it takes for light emitted by distant celestial bodies to reach Earth significantly exceeds the predictions of traditional theories. Moreover, as the distance to the celestial body increases, the delay effect in light propagation time intensifies[21,22]. This phenomenon indicates that the speed of light is relatively slower in more distant regions of space.
- **Superluminal Redshift Phenomenon**: Astronomical observations reveal that when the observation distance exceeds 5 billion light-years, the calculated recession velocity of celestial bodies is often greater than the speed of light, which clearly contradicts the basic assumptions of relativity. According to the spacetime-light speed covariance principle, the lower the relative speed of light, the slower the time progression in that space, and the redshift of its emitted light increases accordingly. This "superluminal" phenomenon precisely illustrates that: in the redshift we observe, in addition to the contribution from the recession velocity of celestial bodies, a significant portion stems from the impact of reduced light speed (and slowed time progression)[23,24]; furthermore, the farther the distance, the greater the redshift caused by the reduction in light speed. Therefore, this abnormal redshift phenomenon indirectly proves that the farther the distance, the relatively slower the speed of light. When the observation distance exceeds approximately 14.3 billion light-years (i.e., the Hubble radius), the current recession velocity of all celestial bodies exceeds the speed of light.
- **Antigravity Field and Spacetime Contraction Effect**: The antigravity field originates from the inward-outward gradient of the speed of light in the universe. According to the spacetime-light speed covariance principle, during the process of decreasing light speed, spacetime undergoes

corresponding contraction: the slowing of time progression causes redshift (as mentioned earlier), while spatial contraction leads to the observed size being smaller than the actual size—a conclusion supported by astronomical observations. When the speed of light approaches zero, time progression nearly stagnates, and spatial intervals contract extremely—this means that even if the universe has a boundary, it will never be reachable for us.

This distribution characteristic of the speed of light is consistent with the evolutionary process of energy diffusion from the center outward after the Big Bang: the central region of the universe is a high-energy space (corresponding to a higher speed of light), while the edge regions are low-energy spaces (corresponding to a lower speed of light). Celestial bodies spontaneously move toward regions with lower light speed, and this process directly drives the expansion of the universe. It is suggested that in dark energy research, more attention should be paid to the relative changes in the speed of light in the universe and the analysis of redshift data, in order to verify the light speed gradient distribution model and provide more evidence for revealing the nature of dark energy.

6. Conclusions

Based on the principles of constant light speed, relative changes in light speed, and the minimum energy principle, this paper constructs the vacuum dynamics theory. Its core is: a light speed gradient ($\nabla c \neq 0$) in vacuum space will cause objects to accelerate spontaneously ($g_m = -\nabla c^2$), with the kinetic energy derived from internal energy. This provides a unified explanatory framework for universal gravitation and dark energy, and lays a theoretical foundation for the propellantless vacuum engine.

Through the covariant relationship between spacetime and light speed, the consistency between this theory and general relativity in describing spacetime laws is clarified. The spacetime-light speed covariance principle reveals the inherent connection between the two, provides an intuitive dynamical explanation for "gravity generated by spacetime curvature", makes up for the dynamical defects of general relativity, and also builds a framework for the unification of gravitational field and electromagnetic field.

In conclusion, the vacuum dynamics theory provides a new understanding of the nature of gravity and dark energy, improves general relativity, and opens up new directions for basic theoretical and applied research in physics.

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