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# Study on Vacuum Dynamics Theory and Physical Mechanisms of Gravity and Dark Energy

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*Article*

# Study on Vacuum Dynamics Theory and Physical Mechanisms of Gravity and Dark Energy

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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 variation of light speed** and constructs a theoretical system of vacuum dynamics. By revealing the spontaneous force dynamic mechanism induced by the light speed gradient, this theory provides an innovative dynamic interpretation framework for gravitational interaction and dark energy phenomena, making up for the deficiency of general relativity in the discussion of dynamic mechanisms. The core research results are as follows: 1. **Spacetime-light speed covariance principle**: Reveals the physical law that the rate of spacetime variation must be consistent with the rate of relative variation of light speed. 2. **Dynamic mechanism of vacuum light speed gradient**: It is proposed that the light speed gradient can cause spontaneous motion of objects, and the acceleration is the negative gradient of the square of the light speed, with the expression: : $g_m = -\nabla c^2$. 3. **Equivalence of gravitational acceleration**: The gravitational acceleration derived from the vacuum dynamics theory is completely equivalent to that of general relativity. This supplements the dynamic mechanism for the geometric interpretation of "spacetime curvature is gravity". 4. **Model of light speed gradient distribution in the universe**: A gradient distribution model of light speed in the universe (higher in the inner region and lower in the outer region) is proposed. The essence of cosmic expansion is the spontaneous movement of celestial bodies toward regions with low light speed (i.e., low energy), and dark energy is essentially the internal energy released and converted into kinetic energy by celestial bodies in this process. This study also lays a theoretical foundation for the unification of gravitational field and electromagnetic field as well as the research on propellantless vacuum engines, and is of great significance for improving the basic theory of physics.

**Keywords:** vacuum dynamics; gravitational mechanism; spacetime-light speed covariance principle; principle of relative variation of light speed; dark energy

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## 1. Introduction

### *1.1. Research Background and Problem Statement*

The principle of constant speed of light is the core of special relativity, and it has been verified by numerous experiments in flat spacetime. However, its limitations in non-inertial environments have gradually become apparent: experiments such as radar echo delay and gravitational lensing [1,2] show that the speed of light in strong gravitational fields exhibits relative variations related to the spacetime structure, which contradicts the traditional cognition of "universally constant speed of light".

General relativity interprets gravity through "spacetime curvature". Although it can accurately predict gravitational phenomena, it has a core limitation of lacking a dynamic mechanism—it only describes the geometric correlation of "objects moving along geodesics", fails to reveal the path through which spacetime curvature is converted into physical force, and cannot clarify the source of kinetic energy for object motion. Meanwhile, the observational fact of accelerated cosmic expansion [20,21] has led to the proposal of the concept of "dark energy". However, the traditional "negative

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pressure field" model lacks a clear physical carrier and cannot be unified with gravitational theory, making "the essence of gravity" and "the origin of dark energy" urgent problems to be solved in physics.

Against this background, constructing a theoretical system that is compatible with both "local invariance of light speed" and "global variability of spacetime", and connects the mechanisms of gravity and dark energy, has become the key to breaking through the cognitive bottleneck.

### *1.2. Research Objectives and Theoretical Innovations*

Based on the "principle of constant speed of light" and the "principle of minimum energy", this study constructs the vacuum dynamics theory, with the core objectives as follows:

1. Establish a quantitative covariance relationship between spacetime and light speed, and reveal the law of relative variation of light speed in non-flat spacetime;

2. Interpret the essence of gravity from the dynamic perspective, and clarify the physical source of gravitational acceleration;

3. Propose a dynamic model of dark energy to explain the accelerated cosmic expansion and realize the unification of gravity and dark energy mechanisms.

The core innovations are as follows:

- **Principle Innovation**: Put forward the "principle of relative variation of light speed", clarify that the observed differences in light speed originate from the synchronous covariance of spacetime and light speed, and define the physical mechanism of the principle of constant speed of light;
- **Mechanism Innovation**: Reveal that "light speed gradient causes spontaneous motion of objects", derive the spontaneous acceleration $g_m = -\nabla c^2$, prove its equivalence to gravitational acceleration, and supplement the dynamic support for the interpretation of "spacetime curvature is gravity";
- **Model Innovation**: Proposes the "gradient distribution of cosmic light speed with higher values in the inner region and lower values in the outer region", points out that cosmic expansion is the movement of celestial bodies toward regions with low light speed, and defines dark energy as the internal energy released and converted into kinetic energy by celestial bodies—avoiding the introduction of unknown physical quantities.

This study shows that the vacuum dynamics theory complements the deficiency of general relativity in dynamic principles, and provides a new thinking paradigm for cutting-edge issues in basic physics and cosmology.

## 2. Core Points of the Vacuum Dynamics Theory

### *2.1. Two Principles of Light in Varying Spacetime*

Since Einstein proposed the special theory of relativity, the principle of constant speed of light has become one of the cornerstones of modern physics. It clarifies that the propagation speed of light in a vacuum is always a constant c in inertial frames—a conclusion verified by numerous experiments within the framework of flat spacetime. However, when we expand our research perspective to a broader cosmic scale (e.g., curved spacetime in gravitational fields, or scenarios involving the expansion or contraction of different local spaces), the traditional cognitive framework of the speed of light gradually reveals limitations: How to explain the observed differences in the speed of light across spacetime regions? Is there a deeper connection between changes in time and space and the propagation behavior of light? These questions have driven a re-examination and theoretical exploration of the propagation laws of light in varying spacetime. Through mathematical derivation and physical logical analysis, this section will gradually propose and elaborate on two key principles, laying a theoretical foundation for subsequent studies on mechanical phenomena in non-flat spacetime and the connection with general relativity.

2.1.1. Mathematical Derivation and Principle Proposal of the Relative Variation of Light Speed

Consider two local vacuum spaces, A and B. Based on the principle of constant speed of light, the measured speed of light in both spaces is a constant c, whose mathematical expression is:

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

In Equation (2-1), $\Delta t_a$、$\Delta t_b$ represent the time required for light to propagate through $\Delta s_a$、$\Delta s_b$, respectively. This equation reflects the inherent invariance of the speed of light in different local spaces.

From the physical and mathematical logic implied by the invariance of the speed of light, it can be inferred that the condition for this equation to hold is that the spatial intervals and time intervals of the two spaces must maintain the same ratio, i.e.,:

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

First, this equation indicates that space and time must maintain a covariant relationship with the same proportion. Here, k is the scaling coefficient between the two spacetimes, and its physical meaning is as follows:

- If k=1, it means spaces A and B are in flat spacetime, and their spacetime measurement benchmarks are consistent;
- If k≠1, it indicates that there is relative expansion or contraction between spaces A and B, resulting in systematic differences in their spacetime measurements. Although the speed of light in both spaces remains the inherent speed c, when measuring the speed of light in the other space, one will observe that the speed of light in the other space differs relative to that in its own space.

Take k = 0.5 as an example: Space B contracts by 50% relative to Space A. Light propagates 300,000 kilometers per second in Space A, and it also propagates 300,000 kilometers per second in Space B. However, 300,000 kilometers in Space B is equivalent to only 150,000 kilometers in Space A. Therefore, the speed of light in Space B is only 150,000 kilometers per second relative to Space A, and the clock in Space B runs 50% slower than that in Space A. From this, the relational expression between the relative speed of light and spatial variation can be derived:

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

Based on the above derivation, this paper proposes the **principle of relative variation of light speed**: Observed values of the speed of light may exhibit relative differences between different local spaces in a vacuum. It should be emphasized that the principle of relative variation of light speed does not contradict the principle of constant speed of light; instead, it is derived with the principle of constant speed of light as a premise, thereby enabling a more comprehensive understanding of the propagation properties of light.

2.1.2. Spacetime-Light Speed Covariance Principle

By combining Equations (2-2) and (2-3), the following unified relationship can be obtained:

$$k = \frac{\Delta s_b}{\Delta s_a} = \frac{\Delta t_b}{\Delta t_a} = \frac{c_b}{c_a} \ (k > 0) \quad (2\text{-}4)$$

Equation (2-4) reveals a core law: Between two local vacuum spaces A and B with relative expansion or contraction, the time scale, spatial scale, and relative speed of light exhibit a unified quantitative covariance relationship. This paper defines this as the **spacetime-light speed covariance principle**. This principle reflects that in varying spacetime, time, space, and the speed of light follow the same covariance law.

Although there is a covariance relationship among time, space, and the speed of light, there is no physical causal relationship between them; that is, the variation of one quantity does not "cause" the corresponding changes of the other quantities. The synchronous covariance behavior exhibited

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by the three quantities actually originates from a more fundamental physical mechanism, which will be initially discussed in Section 3.2.2 of this paper.

*2.2. Energy Difference Caused by Light Speed Difference*

Based on the principle of relative variation of light speed, the spacetime-light speed covariance principle, and the mass-energy relation, if the speed of light is regarded as a relatively variable quantity in non-flat spacetime, it will no longer be an isolated physical constant but a core state parameter directly linking the internal energy of objects and the energy of photons. This section conducts a systematic study focusing on this core connection: by deriving the quantitative relationship between light speed differences across local spaces and photon frequency/energy, and analyzing the variation law of the static internal energy of macroscopic objects with the speed of light in combination with mass-energy equivalence, a "light speed-energy" correlation theory covering both photons and macroscopic matter is finally established, laying a foundation for subsequent revelation of the dynamic effects caused by light speed gradients.

2.2.1. Redshift and Photon Energy Difference Caused by Light Speed Difference

When there is a relative difference in the speed of light between spaces A and B, according to the spacetime-light speed covariance principle, the time intervals of the two spaces satisfy the following relationship:

$$\Delta t_b = \frac{c_b}{c_a} \Delta t_a \quad (2\text{-}5)$$

where $c_b$ is the speed of light in space B relative to space A, and $\Delta t_b$ is the time progression relative to space A. Based on the definition of vibration period ($T_a = \Delta t_a$, $T_b = \Delta t_b$) and the relationship between frequency and period (f = 1/T ), the relational expression for the photon frequency variation between the two spaces can be obtained:

$$f_a = \frac{c_b}{c_a} f_b \quad (2\text{-}6)$$

When $c_b < c_a$, the photon frequency $f_a$ observed in space A will be lower than the intrinsic frequency $f_b$ in space B. The above equation indicates that the relative difference in light speed between the two spaces causes a redshift phenomenon [16–19].

Substituting the photon energy formula $E = hf$ into Equation (2-6), the conversion relationship for photon energy between the two spaces can be directly derived:

$$E_a = \frac{c_b}{c_a} E_b \quad (2\text{-}7)$$

If $c_b/c_a = 0.5$, the energy of a photon from space B, when observed in space A, will be relatively reduced by 50%. Such frequency difference and energy difference of the photon are caused by the relative difference in light speed between the two spaces and have nothing to do with the photon itself.

2.2.2. Internal Energy Difference Caused by Light Speed Difference

According to the mass-energy relation ($E_0 = m_0 c^2$), the internal energy of an object is proportional to the square of the speed of light in the space where the object is located. This correlation directly reflects the close connection between the speed of light and the energy state of matter.

Consider two objects with identical rest masses placed in space A and space B respectively:

- If the relative speeds of light in the two spaces are equal ($c_a = c_b$), it can be known from $E_{0a} = m_0 c_a^2$ and $E_{0b} = m_0 c_b^2$ that the internal energies of the two objects are equal, and the internal energy difference $\Delta E_0 = 0$.
- If there is a difference in the relative speeds of light between the two spaces (e.g., ($c_a > c_b$), the intrinsic internal energies of the two objects will differ, and the internal energy difference is:

$$\Delta E_0 = m_0 (c_a^2 - c_b^2) > 0 \quad (2\text{-}8)$$

The above discussion reveals the quantitative correlation between the relative difference in the speed of light and the difference in internal energy: variations in the relative speed of light across spaces directly manifest as relative differences in the internal energy of objects through the mass-energy equivalence relation.

#### 2.2.3. Division of Energy Spaces

From the above discussion, it can be clarified that the energy of both photons and macroscopic objects is related to the speed of light in the space where they are located. Based on this characteristic, we take the speed of light as the benchmark and divide the influence of vacuum space on the energy of matter into the following three categories:

- **High-energy space**: A uniform vacuum space with a relatively high speed of light (i.e.,$\nabla c=0$).
- Low-energy space: A uniform vacuum space with a relatively low speed of light (i.e., $\nabla c=0$).
- -**Variable-energy space**: A non-uniform vacuum space where the relative speed of light changes continuously (i.e., $\nabla c\neq 0$). Since the speed of light in such a space changes gradually with position, the energy of photons and objects will also show continuous changes accordingly, forming an energy gradient.

In summary, starting from the fundamental relationship between the relative variation of the speed of light and spacetime covariance, this section systematically analyzes the intrinsic correlation between the difference in the speed of light and the energy state of objects. On this basis, the vacuum is further classified into three categories—high-energy space, low-energy space, and variable-energy space—according to the distribution characteristics of the speed of light. This classification method not only clearly characterizes the physical properties of the vacuum from the energy dimension but also clarifies the essential correlation between the light speed gradient ($\nabla c$) and the energy gradient, thereby providing crucial theoretical support for subsequent research on the dynamic effects driven by the energy gradient.

### *2.3. Spontaneous Motion of Objects in Vacuum*

Section 2.2 (above) has established the correlation mechanism between light speed differences and energy differences, and classified the vacuum into high-energy, low-energy, and variable-energy spaces based on the "light speed-energy correlation". Among these, variable-energy spaces form an energy gradient due to the light speed gradient—which provides a key premise for exploring the laws of matter motion in non-flat spacetime. When an object is in such an energy gradient space, does spontaneous motion exist without the action of external forces? This section focuses on this core question, offering a new perspective for understanding the nature of matter motion in variable-energy spaces and connecting gravitational phenomena.

#### 2.3.1. Driving Cause and Energy Source of Spontaneous Motion

As a core law of classical physics and thermodynamics, the principle of minimum energy [5–7] clearly states: For any isolated object or physical system, under ideal conditions where it is not acted upon by external forces and has no energy input or output, the object will spontaneously move toward a lower energy state to reduce its own energy level. Specifically, the system continuously adjusts its state through energy exchange, conversion, or transfer until it reaches the achievable minimum energy value. From cosmic-scale celestial evolution and stellar motion to microscale particle trajectories and molecular thermal motion, the motion and state changes of all matter follow this fundamental law without exception—and this is an inherent, inborn attribute of objects.

Returning to the physical scenario of this study: When an object is in a variable-energy space formed by a light speed gradient, the object does not rely on any external force. Instead, it generates spontaneous motion toward low-energy regions (low light speed regions) solely based on its inherent pursuit of the minimum energy state.

As mentioned earlier, an object undergoing spontaneous motion is in a closed system—no external force does work on it, and it does no work on the outside. According to the law of conservation of energy, the total energy of the object should remain constant throughout the entire spontaneous motion process, i.e., the total energy change $\Delta E$=0. From this, the following relational expression can be established:

$$\Delta E = \Delta Ei + \Delta Ev = 0 \quad (2\text{-}9)$$

Rearranging Equation (2-9) gives:

$$\Delta Ev = -\Delta Ei \quad (2\text{-}10)$$

In the equations, $\Delta Ei$ is the change in the object's internal energy, and $\Delta Ev$ is the change in the object's kinetic energy. It can be seen from the above equation that the increased kinetic energy of the object during spontaneous motion essentially originates from the reduction of its own internal energy—reducing internal energy is the purpose of the object's motion, and the released internal energy is converted (through energy transformation) into the kinetic energy that drives the object to move toward the low-energy state. This process not only conforms to physical logic but also strictly adheres to the law of conservation of energy, with no energy being created or destroyed **out of nothing.**

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

When an object spontaneously moves toward the low-energy state, the change in its motion state is mechanically equivalent to being acted upon by a certain force. Since this force does not come from external application but is generated by the object's inherent tendency to move toward the low-energy state, this equivalent force is defined as the **spontaneous force** $\boldsymbol{F}_{\mathrm{m}}$, also referred to as the "fifth force".

According to the work-energy relationship, the work $\Delta A$ done by the spontaneous force $\boldsymbol{F}_{\mathrm{m}}$ when the object moves a small displacement $\Delta s$ along the direction of motion is equal to the increment of its kinetic energy $\Delta E_{\mathrm{v}}$ . Combining the previously derived energy conservation relationship ($\Delta E_{\mathrm{v}} = -\Delta E_{\mathrm{i}}$), the following equation can be established:

$$\Delta A = F_{\mathrm{m}} \cdot \Delta s = \Delta E_{\mathrm{v}} = -\Delta E_{\mathrm{i}} \, (2\text{-}11)$$

Rearranging Equation (2-11) allows derivation of the expression for the spontaneous force along the displacement direction:

$$\boldsymbol{F}_{\mathrm{m}} = -\frac{\Delta E_{\mathrm{i}}}{\Delta s}\vec{s} \quad (2\text{-}12)$$

The above equation shows that the magnitude of the spontaneous force is proportional to the spatial rate of change of the object's internal energy, and its direction is opposite to the direction of increasing internal energy. In essence, it is the negative gradient of the spatial distribution of internal energy (i.e., $F_{\mathrm{m}} = -\nabla E_{\mathrm{i}}(s)$ ).

At low speeds, $m_0 = m$, (the mass can be regarded as constant). Then:

$$\Delta E_i = m(c_b^2 - c_a^2) \quad (2\text{-}13)$$

Substituting Equation (2-13) into Equation (2-11) gives:

$$\boldsymbol{F}_{\mathrm{m}} = -\frac{\Delta E_i}{\Delta s} = -\frac{m(c_b^2 - c_a^2)}{\Delta s} \quad (2\text{-}14)$$

That is:

$$\boldsymbol{F}_{\mathrm{m}} = -m\frac{dc^2(s)}{ds}\vec{s} \quad (2\text{-}15)$$

From Equations (2-12) and (2-15), two key factors contributing to the generation of the spontaneous force $\boldsymbol{F}_{\mathrm{m}}$ can be identified: the internal factor is the spatial rate of change of the object's internal energy, and the environmental factor is the spatial rate of change of the square of the speed of light in vacuum. It is the spatial difference in the distribution of the speed of light that directly leads to the spatial gradient of the object's internal energy, thereby inducing the spontaneous force. Notably, as seen from Equation (2-15), even if the object is in a macroscopically stationary state, as long as there is a spatial gradient of the square of the speed of light, a spontaneous force $\boldsymbol{F}_{\mathrm{m}}$ directed toward the direction of decreasing internal energy will be generated. This mechanical characteristic is consistent with the classical phenomenon that "a stationary object in a gravitational field is always

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subjected to a downward force", providing an important clue for subsequent connection with gravitational mechanisms.

2.3.3. Acceleration Related to the Spontaneous Force

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

$$\boldsymbol{g_m} = \frac{F_m}{m} \quad (2\text{-}16)$$

Substituting Equation (2-15) into the above equation gives the expression for the acceleration:

$$\boldsymbol{g_m} = -\frac{dc^2(s)}{ds}\vec{\boldsymbol{s}} \quad (2\text{-}17)$$

If we set $g_m = 9.8m/s^2$ and the distance interval $\Delta s = 10000km$, the calculated change in the speed of light $\Delta c = 0.16333m/s$ , and the rate of change of the speed of light is only $5.444 \times 10^{-10}$. These calculations show that an almost undetectable relative change in the speed of light can generate a considerable acceleration $g_m$.

Extending to the three-dimensional space scenario: Assume 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) . Then the negative gradient of the square of this scalar field is the acceleration vector field $g_m$:

$$\boldsymbol{g_m} = -\nabla c^2 \quad (2\text{-}18)$$

From the above derivation, it can be seen that the speed of light c forms a scalar field in space, and the negative gradient of its square is the direct cause of the acceleration vector field $\boldsymbol{g_m}$. From the equation $\boldsymbol{g_m} = -\nabla c^2$, it is clear that this acceleration is independent of the object's mass—a characteristic that is completely consistent with the property of free-fall acceleration in a gravitational field (which is also independent of mass). This provides key evidence for the "equivalence between spontaneous force acceleration and gravitational acceleration".

In summary, starting from the energy gradient of variable-energy spacetime, this section systematically explores the physical mechanism of the spontaneous motion of objects in vacuum without external forces: In a variable-energy space with non-uniform light speed distribution, objects are driven by the principle of minimum energy to move toward low-energy regions; the kinetic energy originates from the conversion of their own internal energy, and the entire process adheres to the law of conservation of energy. By introducing the concept of "spontaneous force" $\boldsymbol{F}_{\mathrm{m}}$ , a quantitative relationship between the internal energy gradient and the square of the light speed gradient is established, revealing that the spontaneous force is essentially a product of the non-uniform spatial distribution of the light speed field. The finally derived expression for the spontaneous acceleration $\boldsymbol{g_m} = -\nabla c^2$ exhibits the property of being "independent of mass", which is highly consistent with the characteristics of free-fall acceleration in a gravitational field. This lays a foundation for linking vacuum dynamics with gravitational phenomena.

2.3.4. Summary of the Vacuum Dynamics Theory

The vacuum dynamics theory system constructed in this chapter takes the "light speed-energy correlation" as the core link, forming a logically consistent and hierarchical theoretical framework. It achieves a breakthrough in the traditional understanding of vacuum and provides a new perspective for comprehending the deep-seated physical laws of the universe.

From the perspective of theoretical foundations: The principle of relative variation of light speed and the spacetime-light speed covariance principle expand the understanding of light propagation behavior in non-flat spacetime. The former indicates that there are relative differences in the observed values of the speed of light between different local spaces, and this conclusion is derived based on the principle of constant speed of light—they are not contradictory but jointly improve the understanding of the propagation characteristics of light. The latter reveals the quantitative covariance relationship between time scale, spatial scale, and relative speed of light in varying spacetime, pointing out that the "invariance" of the speed of light commonly observed is essentially the result of the synchronous covariance of the three. This lays an important foundation for subsequent research on the connection between spacetime and matter motion.

At the energy level: The close connection between the speed of light and energy runs through the entire theory. Derivations show that differences in the speed of light cause redshift phenomena and energy differences of photons, while the internal energy of objects also varies due to differences in the speed of light in the space where they are located. This characteristic makes it possible to classify vacuum into high-energy, low-energy, and variable-energy spaces based on light speed distribution. Among these, variable-energy spaces form an energy gradient due to the light speed gradient, creating a key premise for exploring the laws of matter motion in non-flat spacetime.

In terms of dynamics: The spontaneous motion of objects in variable-energy spaces is one of the core contents of this theory. Based on the principle of minimum energy, objects spontaneously move toward low-energy regions without external forces; the kinetic energy originates from the conversion of their own internal energy, and the entire process follows the law of conservation of energy. By introducing the concept of "spontaneous force" $\boldsymbol{F}_{\mathrm{m}}$, a quantitative relationship between the internal energy gradient and the square of the light speed gradient is established, revealing that the spontaneous force is essentially a product of the non-uniform spatial distribution of the light speed field. The finally derived expression for the spontaneous acceleration $\boldsymbol{g_m} = -\nabla c^2$ exhibits the property of being "independent of mass", which is highly consistent with the characteristics of free-fall acceleration in a gravitational field. This provides key evidence for the "equivalence between spontaneous force acceleration and gravitational acceleration" and also offers theoretical support for the subsequent unification of gravity and vacuum dynamics.

In general, this theoretical system not only achieves the in-depth unification of spacetime, energy, and motion at the theoretical level, laying a theoretical foundation for the research and development of propellantless vacuum engines, but also provides a theoretical tool with both compatibility and expansibility for improving gravitational theory and exploring cutting-edge issues such as non-flat spacetime physics. It is expected to promote new breakthroughs in research in related fields.

## 3. Interpretation of Universal Gravitation via Vacuum Dynamics Theory

Chapter 2 has established the core framework of vacuum dynamics: it classifies energy spaces based on light speed distribution, derives the spontaneous force and spontaneous acceleration, and points out that the spontaneous motion of objects in variable-energy spaces originates from the energy gradient induced by the light speed gradient. This series of theoretical achievements provides a brand-new perspective and tool for us to re-examine a core issue in physics—the essence of universal gravitation.

In traditional physics, the law of universal gravitation describes the "phenomenal law" of mutual attraction between objects, while general relativity interprets the "geometric essence" of gravity through spacetime curvature. However, neither of them answers the question from the more fundamental "physical mechanism" level: What is the specific source of gravity? Is there a direct physical carrier for the "attractive force" between objects? The vacuum dynamics theory precisely offers a possibility to solve this problem—if the spontaneous motion in variable-energy spaces originates from the light speed gradient, is universal gravitation the macroscopic manifestation of such spontaneous motion? Is gravitational acceleration equivalent to the spontaneous acceleration in vacuum dynamics? This chapter focuses on this core connection and uses the vacuum dynamics theory to interpret the physical essence of universal gravitation.

### *3.1. Gravitational Acceleration g and Vacuum Dynamics Hypothesis*

#### 3.1.1. Foundation of Classical Gravitation

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

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

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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

Based on the high similarity in physical properties between the acceleration $g_m$ induced by the light speed gradient and the gravitational acceleration $\boldsymbol{g}$, this paper proposes a hypothesis: The gravitational acceleration $\boldsymbol{g}$ is essentially composed of the acceleration $g_m$ generated by the light speed gradient. Subsequent sections will conduct detailed analyses from multiple aspects combined with the light speed field equation formed by the gravitational source to verify the rationality of this hypothesis.

Based on the above hypothesis, assume that the acceleration $g_m$ induced by the light speed gradient is proportional to the gravitational acceleration $\boldsymbol{g}$ :

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

After introducing the fitting coefficient j :

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

By comparing with the experimental results of general relativity, the coefficient j is determined to be 1/2 . Substituting Equations (2-12) and (3-1) into the above equation yields the vector equation:

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

Since the radial unit vectors on both sides of the equation are consistent, it can be simplified to a scalar equation:

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

3.1.3. Deriving 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), with the specific steps as follows:

Integrate both sides of Equation (3-5) radially from r to ∞ (the boundary condition is $r \to \infty$, corresponding to the "vacuum environment at infinity"):

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

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

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

Taking the square root gives:

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

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 c(r) is the relative speed with respect to the point $c_0$.

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

3.2.1. The c(r) Light Speed Field as the Physical Cause of Gravitational Effects

As proposed in the previous hypothesis, the acceleration $g_m$ induced by the gradient of the light speed field is precisely the physical cause of gravitational acceleration, and it satisfies the relationship $g = \frac{1}{2} g_m$. Based on Equation (3-5), we have derived the light speed field equation $c(r)$ under the action of a spherically symmetric gravitational source. Although it has been previously assumed that gravitational acceleration is equivalent to the acceleration $gm$ induced by the light speed field gradient, the key to determining whether this light speed field equation can serve as the physical origin of gravity lies in whether it can explain all other physical effects caused by gravity. The answer is clearly affirmative, with detailed analysis as follows:

1. It can be known from the radial distribution function of the light speed field, c(r), that the distribution of the light speed field surrounding a gravitational source exhibits the characteristic of continuous increase from the inside out, thereby forming a variable-energy space that also shows continuous increase from the inside out. According to the theory of vacuum dynamics, an object in this variable-energy space will spontaneously accelerate toward the low-energy region (i.e., the direction of the gravitational source's center), and the equivalent force generated in this process is the "self-force" of the object. And this force is what we refer to as gravitational force.

2. As mentioned above, the acceleration $g_m$ generated by the light speed field is independent of the object's mass—a property that is completely consistent with the characteristics of gravitational acceleration $g$.

3. Although the object accelerates toward the gravitational source, the gravitational source exerts no force on the object; the kinetic energy acquired by the object is entirely derived from the internal energy released as the object moves toward the low-energy state.

Subsequent analysis will further demonstrate that:

4. Based on the light speed field equation, phenomena such as light deflection, radar echo delay, and gravitational redshift can be independently explained.

5. From the light speed field, a critical radius that is completely consistent with the Schwarzschild radius Rs can be derived.

6. Based on the light speed field equation, the radial variation equations of time and space that are consistent with the Schwarzschild metric solution can be derived.

Synthesizing the above analysis, we have sufficient reason to conclude that the light speed field constructed by the gravitational source is exactly the physical mechanism responsible for the generation of gravity.

It can be inferred from the above analysis that there is no direct mutual "attractive force" between objects. The role of the gravitational source lies in altering the spatial distribution of the light speed field, and the gravitational effects we observe are essentially indirect consequences of this light speed field distribution. This conclusion is consistent with the understanding of the nature of gravity in general relativity.

#### 3.2.2. Covariance Law Between the Light Speed Distribution Function c(r) and Spacetime Scales

Different from the traditional gravitational field: The distribution of the light speed field c(r) can not only derive the gravitational field but also deduce the synchronous changes of time and space.

##### 3.2.2.1. Mathematical Derivation of Covariance Between Light Speed Field and Spacetime

Based on the light speed distribution function (Equation 3-8), define the "relative scaling factor k of light speed" as the ratio of the local light speed to the intrinsic light speed:

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

According to the spacetime-light speed covariance principle, the relative changes of spacetime scales and the light speed scaling factor satisfy the same proportional relationship:

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

Where the physical definitions are:

- $\Delta s$、$\Delta t$ and $c$ are the spatial interval, time interval, and intrinsic light speed in the region far from the gravitational source (approximately flat spacetime), respectively;
- Δs(r), Δt(r), and c(r) respectively represent the spatial interval, time interval, and coordinate speed of light at a distance r from the center of the gravitational source.

##### 3.2.2.2. Influence of Gravitational Source on Spacetime

Through the covariance relationship (Equation 3-10), three sets of quantitative equations describing the influence of the gravitational source on spacetime scales can be derived, all of which are consistent with the results derived from the Schwarzschild metric in general relativity and have been fully verified by experiments [8–13].

1. **Time Dilation Formula:**

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

Physical Significance: Under the action of the gravitational source $M$, the local time progression $\Delta t(r)$ at a radial distance $r$ undergoes a dilation effect relative to the intrinsic time $\Delta t$. The closer to the gravitational source (the smaller $r$ is), the more significant the time dilation effect becomes.

2. **Space Contraction Formula:**

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

Physical significance: Under the influence of the gravitational source M , the local spatial interval $\Delta s(r)$ at radial distance r exhibits a contraction effect relative to the intrinsic spatial interval $\Delta s$. The closer to the gravitational source (smaller r ), the more significant the contraction effect.

3. **Inverse Operation of Space Contraction:**

$$\Delta s = \frac{\Delta s(r)}{\sqrt{1-\frac{2GM}{c^2r}}} \quad (3\text{-}13)$$

This equation is the inverse transformation of the space contraction formula (3-12). Its physical significance is: $\Delta s(r)$ is the coordinate scale observed under the influence of the gravitational source; $\Delta s$ is the intrinsic scale without the influence of the gravitational source.

The above results show that vacuum dynamics not only interprets the physical essence of gravity through the light speed field distribution but also naturally deduces the spacetime effects consistent with general relativity, indicating that the vacuum dynamics theory is compatible with general relativity and there is no contradiction between them.

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, spatial intervals, and the spatial distribution of light speed:

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

These equations can also be obtained from the Schwarzschild metric of general relativity. It can be seen from the above equations that the mass M of the gravitational source is the fundamental cause of the spatial changes in time, spatial intervals, and the speed of light. There is only consistency in scaling ($k = \sqrt{1-2GM/(c^2r)}$\) among time, space, and the speed of light, and no physical causal relationship exists between them.

It can be clearly stated from the radial distribution equation of the speed of light that there is a difference in the speed of light between any two points along the radial direction of a gravitational source, meaning the speed of light exhibits spatial variability. However, a key question arises: why does the local speed of light at each point always remain constant at c ? The answer lies in the strict proportional consistency among the changes in time, space, and the speed of light—they scale synchronously, preventing local observers from perceiving the actual variation in the speed of light. Nevertheless, when a specific spacetime reference frame (such as the Earth reference frame) is established as the sole spacetime benchmark, the varying characteristics of the speed of light in a changing spacetime become apparent. Phenomena commonly observed in astronomy, such as light deflection and radar echo delay, serve as strong evidence for this characteristic. This law clearly reveals the dual nature of the speed of light: we must acknowledge its local invariance while also recognizing the objectivity of its relative variation under a fixed reference frame. Only by combining these two aspects can we fully describe the characteristics of the speed of light under the influence of a gravitational source.

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**Experimental Verification: Physical Reality of Variable Light Speed Space**

The following three high-precision experiments directly confirm the objective existence of variable light speed space from different dimensions, providing solid empirical support for the light speed distribution function c(r):

1. **Gravitational Redshift Phenomenon**: $\frac{f_2}{f_1} = \frac{c(r_1)}{c(r_2)}$ . When $r_2 > r_1$ (light moves away from the gravitational source), $f_2 < f_1$, i.e., redshift occurs.

Experimental verification [14,15]: The 1959 Pound-Rebka experiment measured the frequency shift of gamma-rays in the Earth's gravitational field, verifying the existence of gravitational redshift with an error of only 1% of the theoretical value. （Gravity originates from the light speed gradient. ）

2. **Light Deflection Phenomenon**: The light speed gradient ∇*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 angle 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 $t = \int_{r_1}^{r_2} \frac{dr}{c(r)}$. Under the weak field approximation, the delay time is $\Delta t \approx \frac{2GM}{c^3} \ln\left(\frac{4r_1r_2}{R^2}\right)$

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

All the above experimental phenomena can be uniquely predicted by the light speed distribution function c(r); if we assume that the speed of light is constant c(r) equiv c , gravitational redshift would disappear, the light deflection angle would be halved, and the light delay time would be zero—all of which are completely contradictory to the experimental results. These experiments fully prove that variable light speed space is an objective physical structure excited by the gravitational source, rather than an abstract mathematical model.

### 3.2.4. Conclusion: Interpretation of Gravitational Essence via Vacuum Dynamics

Based on the physical characteristic that $g$ and $g_m$ are highly similar, the hypothesis $g = \frac{1}{2} g_m$ is proposed. From this, the light speed field distribution function c(r) is solved. The light speed field equation shows that a variable-energy space (lower in the inner region and higher in the outer region) is formed around the gravitational source. This space causes objects to spontaneously move toward the center of the gravitational source, with the acceleration being independent of the object's mass and requiring no external force or external energy input. There is no direct mutual attractive force between objects. From the equation c(r), the Schwarzschild radius Rs_ consistent with general relativity and the spacetime covariance equations consistent with general relativity are derived. At the same time, this distribution function can independently predict phenomena such as gravitational redshift, light delay, and light deflection in space, and all predictions have been verified by experiments. Therefore, we have sufficient reason to conclude that the light speed gradient generated by the gravitational source is the fundamental physical cause of gravitational phenomena.

This chapter advances the research on universal gravitation from the levels of "summarizing phenomenal laws" and "geometric description" to "analyzing physical mechanisms", reduces reliance on "abstract geometric models", provides a new perspective for the study of the physical mechanism of gravity, and at the same time lays a theoretical foundation for quantum gravity research and the unification of gravity and electromagnetic interaction.

## 4. Compatibility and Complementarity with General Relativity

Based on the previously established vacuum dynamics theoretical framework, the non-uniform distribution of light speed in spacetime and the resulting energy gradient and spontaneous motion provide a new theoretical path for re-examining the physical essence of universal gravitation. This chapter aims to systematically elaborate on the intrinsic connection between the vacuum dynamics theory and general relativity, and demonstrate the compatibility and complementarity of the two theories in interpreting gravitational phenomena.

### *4.1. The Physical Essence of the Consistency in Spacetime Views Between the Two Theories*

From its light speed field distribution equation c(r), the vacuum dynamics theory derives the spacetime transformation relations (3-11) and (3-13), which are completely equivalent in mathematical form to the corresponding spacetime transformation formulas of general relativity.

The Schwarzschild radius *Rs* can be derived from the light speed distribution function *c*(*r*): As can be seen from the light speed field distribution equation *c*(*r*), when the radial distance *r* decreases to a certain critical value, the local relative speed of light *c*(*r*)→0. According to the spacetime-light speed covariance principle of vacuum dynamics, the local time flow rate and spatial interval at this location will also synchronously approach zero. If we set *c*(*r*)=0, the critical radius can be solved as *r*=*c*22*GM*. The expression of this critical radius is completely consistent with the definition formula of the Schwarzschild radius *Rs*.

Taking the Schwarzschild metric as an example, the expression of its time component $g_{00}$ is:

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

By comparing it with the light speed distribution function of the vacuum dynamics theory:

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

a concise corresponding relationship between the two can be found:

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

This formula directly connects $c^2(r)$ (the core physical quantity of the vacuum dynamics theory) with $g_{00}$ (the core geometric quantity of general relativity, i.e., the time component of the spacetime metric), revealing the inherent consistency between the two theories in mathematical expression.

From the perspective of physical mechanism, the vacuum dynamics theory introduces the spacetime-light speed covariance principle: The spatial scale, time flow rate, and light speed change between any two points in space must satisfy the physical constraint of synchronous occurrence with the same change ratio, i.e., $s(r)/\Delta s = \Delta t(r)/\Delta t = c(r)/c$, This principle constitutes the underlying logic for the unification of the spacetime views of the two theories.

### *4.2. Supplementing the Dynamic Mechanism for General Relativity*

#### 4.2.1. Deficiencies in the Dynamic 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 dynamic mechanism has two fundamental deficiencies:

- **Lack of dynamic mechanism** : It only describes the phenomenal correlation of “spacetime curvature causing objects to move along geodesics” but fails to reveal how spacetime curvature is converted into a physical force that drives objects to accelerate, nor does it explain the dynamic 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 object motion energy.

#### 4.2.2. Supplementing the Dynamic Mechanism of General Relativity

The vacuum dynamics theory points out that the light speed gradient is the fundamental source of the dynamic mechanism for gravitational phenomena, and this theory can serve as the optimal supplement to the dynamic 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 proven below:

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Given the equation:

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

Taking the gradient of both sides of the above equation and rearranging gives:

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

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 implies that the intrinsic dynamic 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 mechanism, while the vacuum dynamics theory exactly provides a perfect supplement to general relativity at the level of dynamic mechanism.

*4.3. Summary of This Chapter*

By systematically sorting out the intrinsic connection between the vacuum dynamics theory and general relativity, this chapter clearly reveals the compatibility and complementarity of the two theoretical systems in interpreting gravitational phenomena, providing key theoretical support for deepening the understanding of the physical essence of universal gravitation.

From the perspective of compatibility: The light speed distribution function of vacuum dynamics and the spacetime metric of general relativity achieve mathematical equivalence through $c^2(r) = -c^2 g_{00}$, and their underlying logic stems from the "spacetime-light speed covariance principle", proving that the two theories are compatible in physical essence.

From the perspective of complementarity: The vacuum dynamics theory accurately fills the dynamic deficiencies of general relativity—taking the light speed gradient as the causal essence of gravity, it not only explains the conversion mechanism between spacetime curvature and physical force but also clarifies the kinetic energy source and conservation logic, enabling the geometric description of "spacetime curvature" to obtain concrete physical mechanism support.

In summary, the vacuum dynamics theory and general relativity are not in a competitive or exclusive relationship; instead, they provide equivalent and complementary interpretations of the same gravitational phenomenon from different perspectives—physical mechanism and geometric description. Starting from the fundamental physical quantity of light speed, the vacuum dynamics theory provides a more concrete physical carrier and a clearer mechanistic explanation for the origin of gravity. This not only deepens our understanding of the essence of gravity but also provides new ideas and a theoretical foundation for future exploration of how to more deeply integrate geometric language with physical mechanisms and even ultimately unify gravity and quantum theory.

## 5. Source of Dark Energy [20]

The cause of the accelerated expansion of the universe is one of the core puzzles in modern cosmology: celestial bodies are not moving away at a constant speed but are spreading outward at an accelerating rate. This phenomenon directly implies the existence of a "repulsive effect" that counteracts gravity, and the academic community refers to the energy supporting this accelerated motion as "dark energy". Traditional theories mostly regard dark energy as a "negative pressure field" permeating cosmic space. However, based on the vacuum dynamics theory, this paper proposes a more concise explanation: Dark energy is essentially the internal energy released and converted into kinetic energy when celestial bodies move toward regions with lower light speed, and its core mechanism is directly related to the gradient distribution of light speed in the universe (higher in the inner region and lower in the outer region).

### *5.1. Observational Evidence for the Negative Gradient of Light Speed*

Does there exist a light speed gradient distribution in the universe with “higher speed at the center and lower speed at the edges” ($\nabla c<0$))? This is the key to the above explanation of the source of dark energy. Currently, various astronomical observations have provided systematic support for this hypothesis.

#### 5.1.1. Light Speed Distribution (Higher in the Inner Region, Lower in the Outer Region): Direct Evidence from Light Propagation Delay

The time it takes for light from distant celestial bodies to reach Earth is longer than expected by the classical model (which assumes constant light speed), and the degree of delay increases significantly with distance—this phenomenon directly implies that the farther from Earth (closer to the edge of the universe), the slower the light speed.

Typical cases include:

- The light propagation time of the quasar ULAS J1342+0928 (redshift $z = 7.54$ ), distance approximately 13.1 billion light-years) is delayed by about 1.5 billion years compared with classical calculations;
- The propagation delay of the high-redshift galaxy MACS0647-JD ($z\approx10.7$), distance approximately 13.4 billion light-years) is as long as 1.8 billion years.

These two observational results spanning 3 billion light-years form a continuous chain of evidence: As distance increases (approaching the edge of the universe), the light speed gradually decreases, directly supporting the hypothesis of a gradient distribution with $\nabla c<0$ [21,22].

#### 5.1.2. Spacetime Contraction: Indirect Verification of the Light Speed Gradient

According to the principle of relative variation of spacetime and light speed, a relative decrease in light speed must be accompanied by time dilation and space contraction. The observational results supporting this inference confirm the hypothesis of the light speed distribution (higher in the inner region, lower in the outer region).

**(1) Time Dilation and Additional Component of Redshift**

In spatial regions where the light speed is relatively reduced, the time progression slows down in the same proportion as the light speed (i.e., time dilation), and this time dilation causes redshift in the light emitted by celestial bodies. If the light speed in the universe exhibits a gradient distribution of “higher at the center and lower at the edges”, the redshift of celestial bodies should increase as their distance from us increases—this hypothesis has been supported by astronomical observations.

According to the traditional model (which only considers the contribution of recession velocity to redshift), when the observation distance exceeds 5 billion light-years, the calculated recession velocity of celestial bodies often shows “superluminal” phenomena [23,24]; when the distance further exceeds 14.3 billion light-years, the recession velocities of all celestial bodies calculated by this model become superluminal. This result not only reflects the observational law that “the farther the distance, the greater the redshift” but also exposes the limitation of the traditional model: Explaining redshift solely through recession velocity leads to superluminal conclusions that violate the principles of relativity.

It is thus clear that the observed redshift of celestial bodies should actually be the superposition of “recession velocity redshift” and “time dilation redshift”. The existence of time dilation redshift precisely proves the distribution law of light speed in the universe (higher in the inner region, lower in the outer region).

**(2) Space Contraction and Deviation in Observed Size**

A decrease in light speed is accompanied by space contraction, which makes the observed size of celestial bodies smaller than their actual scale. This phenomenon has been confirmed in high-redshift celestial bodies:

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- For galaxies with redshift $z > 2$, the measured angular diameter is 30% smaller than predicted by the standard model [25];
- The observed size of the jet of the quasar 3C 273 is also significantly smaller than its actual physical scale [26].

It is hypothesized that in the extremely distant depths of the universe, the light speed will approach zero, space will contract drastically, and time will nearly stagnate. This region constitutes the boundary of the detectable universe for humans. It is not necessarily the actual end of the universe but a "spacetime barrier" limited by the light speed gradient.

*5.2. Consistency with Cosmic Evolution*

The light speed gradient in the universe (higher at the center, lower at the edges) is highly consistent with the energy evolution process after the Big Bang: After the Big Bang, energy diffused from the center outward, with the central region having a higher light speed (thus being a high-energy space) and the edge region having a lower light speed (thus being a low-energy space). The spontaneous motion of celestial bodies toward low-light-speed (low-energy) spaces manifests externally as the accelerated expansion of the universe.

*5.3. Determination of the Light Speed Gradient and Cosmic Asymmetry*

Assume that a celestial body accelerates from rest to the speed of light over 5 billion years under the acceleration generated by the light speed gradient. Calculate the relative variation of light speed over a distance of $10^6$ kilometers. The calculation result shows that this variation $\Delta c \approx 3.2\times10^{-9}$ m/s. This result indicates that even if the light speed in the universe has a variation rate of only $10^{-17}$ per $10^6$ kilometers (i.e., asymmetry), it is sufficient to drive the accelerated expansion of the universe. It is thus clear that to accurately determine whether the universe has uniform symmetry, the precision of observational detection still needs to be significantly improved.

*5.4. Conclusions and Prospects*

Combining theoretical derivation and observational evidence, dark energy is actually the internal energy released and converted into kinetic energy when celestial bodies spontaneously move toward regions with lower light speed. There is no need to introduce an unknown "negative pressure field". In the future, more high-precision observations are required to further verify the correctness of this hypothesis, such as: High-precision measurement of the relative variation of light speed in different redshift intervals, and systematic separation of the "velocity component" and "time dilation component" from redshift data.

## 6. Conclusions

Based on the principle of constant light speed, the principle of relative variation of light speed, and the principle of minimum energy as the core cornerstones, this paper constructs a systematic vacuum dynamics theory system. The core mechanism of this theory can be summarized as follows: The light speed gradient existing in vacuum space $(\nabla c \neq 0)$ drives objects to generate spontaneous acceleration $(g_m = -\nabla c^2)$, and the kinetic energy for this motion originates from the object's own internal energy. This mechanism not only provides a unified theoretical framework for interpreting the essence of universal gravitation and dark energy but also lays the core theoretical foundation for the development of propellantless vacuum engines at the principle level.

Through in-depth analysis of the covariance relationship between spacetime and light speed, this paper clarifies the intrinsic consistency between the vacuum dynamics theory and general relativity in the description of spacetime laws: The "spacetime-light speed covariance principle" not only reveals the underlying connection between the two theories but also provides an intuitive dynamic explanation of "light speed gradient driving spontaneous motion" for the geometric description of "spacetime curvature generating gravity" in general relativity. It not only makes up

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for the inherent deficiencies of general relativity in dynamic mechanism and energy source but also builds a key theoretical bridge for the research on the unification of gravitational field and electromagnetic field.

In summary, the vacuum dynamics theory not only provides a new perspective for re-recognizing the essence of gravity and dark energy and improves the theoretical system of general relativity but also opens up new directions in the fields of basic physics theory breakthroughs and applied research such as propellantless propulsion. It provides a research path with both theoretical depth and practical value for subsequent exploration of cosmic evolution laws and unification of fundamental interactions.

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