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Vacuum Dynamics: Spontaneous Motion Driven by Light Speed Gradient and the Physical Essence of Gravity

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Abstract

Based on the principle of constant speed of light and the principle of minimum energy, this paper constructs a theoretical system of vacuum dynamics, revealing a complete physical causal chain: "light speed gradient → rest energy difference → spontaneous force → spontaneous motion". The core dynamic equation is derived as $g_m = -\nabla c^2$. Applying this theory to the study of gravitational mechanisms, we successfully deduce Newton's gravitational expression $g_N = -\frac{1}{2}\frac{dc^2}{dr}$ from the light speed distribution function, achieving the unification of the mathematical form and physical mechanism of gravity at the level of energy conversion mechanism for the first time. This research not only provides a novel dynamic perspective for analyzing the physical origin of gravity but also verifies the feasibility of propellantless propulsion technology in vacuum in principle.

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1. Introduction

Studies have shown that between relatively expanding spatial regions, differences exist not only in spatial intervals and temporal processes but also in the energy possessed by matter. Based on this energy difference, matter spontaneously moves toward regions with lower energy—this constitutes the physical origin of the dynamic effects exhibited by universal gravitation, spacetime curvature, and dark energy.

In any local domain of relatively expanding space, the locally measured speed of light is uniformly c, which constitutes the absolute aspect of the constancy of the speed of light. However, the speed of light also has another aspect of relative differences between local domains: the local speed of light and the relative speed of light (coordinate speed of light) in other regions have a light speed difference. This relative light speed difference is an important signature physical quantity of the energy difference between two spaces. From this, we obtain the expression for the acceleration acquired by an object in vacuum: $g_m = -\nabla c^2$, and the gravitational field strength expression: $g_N = \frac{1}{2}\, g_m$. Particularly in a space with a light speed gradient, objects will undergo spontaneous accelerated motion without the need for external forces—laying a theoretical foundation for the possibility of propellantless propulsion technology. This paper will systematically elaborate on these viewpoints from two dimensions: theoretical derivation and experimental verification.

2. Covariant Relationship Between Time, Space, and the Speed of Light

2.1. Spacetime-Light Speed Covariance

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Consider two inertial spaces *A* and *B* undergoing relative expansion in vacuum, with an expansion scaling factor *k*. When a beam of light passes through spaces *A* and *B* sequentially, observers in both spaces measure the speed of light as the constant *c*. This raises a fundamental question: Why do measurements of the same light beam yield the identical constant *c* despite the differing spacetime scales of *A* and *B*?

A plausible explanation is that the speed of light undergoes a *k*-fold relative change synchronously with spacetime. This synchronization ensures that the locally measured speed of light remains consistent in both *A* and *B*. Based on this premise, the following covariant relationships between spacetime and the speed of light are derived:

$$\Delta t_{ba} = k\Delta t_a \qquad (2\text{-}1)$$

$$\Delta s_{ba} = k\Delta s_a \qquad (2\text{-}2)$$

$$c_{ba} = kc_a \qquad (2\text{-}3)$$

Combining and rearranging the above equations yields:

$$k = \frac{\Delta s_{ba}}{\Delta s_a} = \frac{\Delta t_{ba}}{\Delta t_a} = \frac{c_{ba}}{c_a} \qquad (2\text{-}4)$$

In these expressions:

- Δt_{ba}, Δs_{ba}, and c_{ba} denote the relative quantities of space *B* with respect to space *A*;
- Δs_a, Δt_a, and c_a represent the proper quantities of space *A*.

Equation (2-4) is an inevitable result of ensuring that the locally measured speed of light equals *c* in both *A* and *B*. It is important to clarify that *cba* refers to the speed of light in space *B* relative to space *A*.

The aforementioned proportional relationship (2-4) reveals a crucial law: In a varying spacetime, to maintain the locally measured speed of light as a constant *c*, time, space, and the speed of light must adhere to this synchronous variation relationship. Therefore, this covariant law is defined as the “Spacetime-Light Speed Covariance Principle”.

2.2. Examples of Spacetime-Light Speed Covariance

Consider a spherically symmetric gravitational source with mass *M*. Within the framework of general relativity [1,2,9], the expressions for physical quantities in the curved spacetime around the source as functions of the radial coordinate *r* can be written as follows:

- Coordinate distribution function of the speed of light:

$$c(r) = kc \qquad (2\text{-}5)$$

- Variation of coordinate time interval:

$$\Delta t(r) = k\Delta t \qquad (2\text{-}6)$$

- Variation of coordinate space interval:

$$\Delta s(r) = k\Delta s \qquad (2\text{-}7)$$

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- Scaling factor:

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

Here:

- Δt, Δs, and c denote the proper time interval, proper space interval, and speed of light at a location far from the gravitational source ($r \to \infty$), respectively;
- $\Delta t(r)$, $\Delta s(r)$, and $c(r)$ represent the relative quantities with respect to the proper quantities at the radial coordinate r;
- G is the gravitational constant, M is the mass of the gravitational source, and r is the radial distance from the point to the center of the gravitational source.

Combining the above equations yields:

$$k = \frac{s(r)}{\Delta s} = \frac{t(r)}{\Delta t} = \frac{c(r)}{c} \qquad (2\text{-}9)$$

Within the interval $R<r<\infty$ (where R is the radius of the gravitational source), the space interval, time interval, and speed of light are all governed by the same scaling factor k. Although the coordinate speed of light $c(r)$ varies with r, the locally measured speed of light remains constant at c at any radial point r due to the proportional covariance of spacetime scales.

Experimental observations indicate that the redshift phenomenon of light, the refraction phenomenon of light, and the time delay phenomenon of light in space are all closely related to the coordinate speed of light $c(r)$; therefore, the coordinate speed of light is one that possesses practical physical significance.

3. There Exist Energy Differences Between Local Vacuum Regions

The expansion or contraction of vacuum space is not only a change in geometric scale but also accompanied by the synchronous variation of the speed of light, time, and space. It is precisely this relative difference that gives rise to energy discrepancies in the matter contained between different local spatial regions.

3.1. Energy Difference of Photons Between Local Spaces A and B

Let k be the expansion scaling factor of space B relative to space A. According to the Spacetime-Light Speed Covariance Principle, the time flow rates of the two spaces satisfy the following relationship:

$$\Delta t_{ba} = k \Delta t_a \qquad (3\text{-}1)$$

where Δt_a denotes the proper time interval of space A, and Δt_{ba} represents the time flow rate of space B relative to space A. If $k<1$, it indicates that the clock in space B runs slower than that in space A. Due to the differing temporal progression in A and B, there exists a discrepancy in the measured frequency of the same periodic phenomenon (e.g., a light wave), with the specific relationship expressed as:

$$f_{ab} = k\, f_b \qquad (3\text{-}2)$$

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Here, f_b is the proper frequency of the photon in space *B*, and f_{ab} is the frequency observed in space *A*. Substituting the photon energy formula (*E=hf*) [3] into the above frequency relationship yields:

$$E_{ba} = kE_b \qquad (3\text{-}3)$$

When *k*<1, the energy E_{ba} of a photon originating from space *B* (with a slower clock) as measured in space *A* is lower than its proper energy E_b in space *B*.

It is crucial to clarify that the photon does not gain or lose energy during propagation; the observed energy difference stems from the disparity in temporal progression between regions *A* and *B*, which results in different measurement outcomes for the same photon's energy. In fact, this energy difference inherently exists from the moment the photon is generated.

3.2. Relative Rest Energy Difference Caused by Relative Light Speed Difference

The preceding analysis demonstrates that based on the relative expansion between spaces *A* and *B*, the relative difference in the speed of light between the two spaces can be derived. Einstein's mass-energy equivalence [4] indicates that the rest energy of an object is directly proportional to the square of the speed of light in its respective spacetime background, expressed as:

$$E_0 = m_0 c^2 \qquad (3\text{-}4)$$

Since the speed of light in the mass-energy equivalence is a core factor influencing rest energy, a relative difference in the speed of light necessarily gives rise to a relative difference in rest energy.

Consider two objects with the same rest mass m_0 located in spaces A and B respectively. The relative rest energy difference ΔE_0 between the two objects is:

$$\Delta E_0 = m_0(c_a^2 - c_{ba}^2) = m_0 \Delta c^2 \qquad (3\text{-}5)$$

This equation shows that if a relative light speed difference exists between the two spaces, a rest energy difference ΔE_0 between the two objects is inevitable.

From a macroscopic perspective, in two relatively expanding inertial spaces, although the physical laws share the same mathematical form, the relative differences in temporal progression, spatial intervals, and the speed of light inherently determine the existence of relative energy differences between matter and material motion in the two spaces. The aforementioned discussion specifically concretizes and quantifies this energy difference.

3.3. The "Energy Topography" of Space

From an energy perspective, the vacuum is not a flat physical background; the relative differences in the speed of light caused by spatial expansion give rise to energy discrepancies between matter in different local regions. Based on the distribution of the speed of light in vacuum, space can be classified into three typical types of energy spaces:

- High-energy space: Corresponding to regions with a relatively high speed of light;
- Low-energy space: Corresponding to regions with a relatively low speed of light;
- Variable-energy space: Corresponding to regions where the speed of light changes continuously.

Variable-energy space, characterized by a continuous variation of the speed of light, is a crucial physical cause driving material motion and will be the focus of our subsequent research. It should be noted that the locally measured speed of light in all three types of regions is *c*, and the speed of light mentioned above refers to the relative speed of light.

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4. Spontaneous Motion in Vacuum

Since the relative difference in the speed of light in vacuum gives rise to a difference in the rest energy of objects, does this energy difference induce the motion of objects? The answer is affirmative.

4.1. Motive Cause of Spontaneous Motion of Objects: The Principle of Minimum Energy

The principle of minimum energy [5] states that every physical system possesses an inherent tendency to evolve toward its possible lowest energy state. Therefore, when an object is located in a variable-energy space formed by a light speed gradient, it will spontaneously move toward the low-energy region (low light speed region) to place itself in the lowest energy state. This is the cause of the spontaneous motion of all matter.

4.2. Energy Conservation in Spontaneous Motion

If the spontaneous motion of an object toward a lower energy state occurs in a closed system—where no external force does work on the object and the object does no work on its surroundings—the total energy of the system shall remain constant during the spontaneous motion in accordance with the law of conservation of energy, i.e., the total energy change ΔE=0. Based on this, the following relationship can be established:

$$\Delta \mathrm{E} = \Delta E_s + \Delta \mathrm{E_k} = 0 \qquad (4\text{-}1)$$

From Equation (4-1), we derive:

$$\Delta E_k = -\Delta E_s \qquad (4\text{-}2)$$

Here, ΔEs denotes the change in the object's rest energy, and ΔE_k represents the change in the object's kinetic energy. Equation (4-2) indicates that the kinetic energy gained by the object during spontaneous motion originates from its own rest energy. The conversion of rest energy to kinetic energy is an inevitable physical process that enables the object to move toward a space with lower rest energy.

4.3. Derivation of the Equivalent Force Fm

If an object accelerates toward a region of lower light speed under conditions where no external force does work on it and the object does no work on its surroundings, this acceleration is equivalent to the object being acted upon by a force. This force, denoted as Fm, is the spontaneous force driving the object's motion toward the low-energy space.

Suppose the object accelerates under the action of the spontaneous force Fm, and the work done by this force is ΔA. According to the work-energy principle:

$$\Delta A = F_{\mathrm{m}} \cdot \Delta s \qquad (4\text{-}3)$$

Rearranging gives:

$$F_{\mathrm{m}} = \frac{\Delta A}{\Delta s} \qquad (4\text{-}4)$$

The work ΔA is equal to the increment in the object's kinetic energy ΔE_k, i.e.:

$$\Delta A = \Delta E_k \qquad (4\text{-}5)$$

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From the previously derived relation $\Delta E_k = -\Delta E_s$, we substitute to obtain:

$$\Delta A = -\Delta E_s \qquad (4\text{-}6)$$

Substituting Equations (4-5) and (4-6) into Equation (4-4), the expression for the force is derived as:

$$F_{\mathrm{m}} = \frac{\Delta A}{\Delta s} = \frac{\Delta E_k}{\Delta s} = -\frac{\Delta E_s}{\Delta s} \qquad (4\text{-}7)$$

Substituting the rest energy change $\Delta E_s = m\Delta c^2$ into the above equation:

$$F_{\mathrm{m}} = -\frac{\Delta E_s}{\Delta s} = -m\frac{\Delta c^2}{\Delta s} \qquad (4\text{-}8)$$

Expressed in terms of the gradient of the square of the speed of light ∇c^2:

$$F_{\mathrm{m}} = -m\nabla c^2 \qquad (4\text{-}9)$$

Equation (4-9) indicates that the spontaneous force *Fm* is proportional to both the mass of the object and the gradient of c^2.

4.4. Acceleration gm Generated by the Spontaneous Force

Based on Newton's second law (*F=ma*) and combined with the expression for the spontaneous force (Equation 4-9), the acceleration *gm* generated by the spontaneous force can be derived as:

$$g_m = \frac{F_{\mathrm{m}}}{m} = \frac{-m\nabla c^2}{m} = -\nabla c^2 \qquad (4\text{-}10)$$

Thus, we obtain a crucial formula: $g_m = -\nabla c^2$. In a space with a light speed gradient ∇c^2, an object will move with an acceleration of *gm*.

Equation (4-10) also indicates that the acceleration *gm* acquired by the object is independent of its mass. This is because the force acting on the object is not an external force but the internal spontaneous force *Fm*—the magnitude of *Fm* is proportional to the object's mass *m*. Consequently, the mass terms in the numerator and denominator cancel out, as shown in Equation (4-10), leading to the mass-independence of *gm*. It follows that if an object's acceleration is independent of its mass, the driving force must be an internal spontaneous force. Therefore, the gravitational force experienced by an object should also be a spontaneous force rather than an external force.

In a space with a light speed gradient, a stationary object will exert a static pressure directed toward the low light speed region ($F_{\mathrm{m}} = -m\nabla c^2$). In the absence of external constraints, the object will move with acceleration *gm*. Since this acceleration is independent of mass, the object does not perceive any force acting on it—a state that can be understood as "weightlessness." Naturally, this is another effect induced by the spontaneous force.

5. Summary of Vacuum Dynamics Theory

Based on classical physics, this paper constructs a logically consistent theoretical framework—Vacuum Dynamics—through a series of progressive derivations. Starting from the principle of the constancy of the speed of light, the theory gradually reveals the inherent and profound connections among spacetime, energy, and motion.

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Core Principles and Key Relationships:

1. **Spacetime-Light Speed Covariance Principle**: Adhering to the core premise of the constancy of the local speed of light, spacetime scales and the speed of light undergo synchronous variations as an integrated whole. This principle uncovers that spacetime and the speed of light possess a deeper-level physical correlation.
2. **Correlation Between Relative Light Speed Difference and Rest Energy Difference**: The relative difference in the speed of light between different spatial points directly reflects the rest energy difference of objects, with the quantitative relationship expressed as $\Delta E_0 = m_0 \Delta c^2$.
3. **Rest Energy Difference Induces Spontaneous Motion**: In accordance with the principle of minimum energy, rest energy differences drive objects to undergo spontaneous motion. During the motion, kinetic energy and rest energy are mutually convertible, satisfying $\Delta E_k = -\Delta E_s$, and the law of conservation of energy is strictly observed throughout the process.
4. **Mechanical Characteristics of Spontaneous Motion**: The equivalent spontaneous force corresponding to spontaneous motion is $F_{\mathrm{m}} = -m\nabla c^2$, with an acceleration of $g_m = -\nabla c^2$. Notably, this acceleration is independent of the object's mass, and the object exhibits a "weightlessness" state during the accelerated motion.

Although Vacuum Dynamics constitutes a logically consistent theoretical system, its validity still requires verification through experiments and applications. Two core verification directions are proposed:

- **Experimental Verification**: Construct a vacuum space with a light speed gradient in the laboratory and observe whether objects exhibit the expected spontaneous acceleration. Successful verification would bring groundbreaking advancements to the aerospace field.
- **Theoretical Verification**: Utilize the Vacuum Dynamics theory to explain the physical mechanism of gravity, further refining the understanding of the essence of gravity. Meanwhile, reconciling this theory with traditional gravitational theories serves as another effective validation of Vacuum Dynamics.

6. Vacuum Dynamics Interpretation of Universal Gravitation

The preceding research indicates that the motion induced by the spontaneous force shares several crucial common characteristics with the motion caused by gravitation—such as the mass independence of acceleration. Starting from the light speed distribution function corresponding to gravitational sources, this section explores and demonstrates that gravitation is a specific manifestation of Vacuum Dynamics under particular scenarios.

6.1. Light Speed Distribution Law of Spherically Symmetric Gravitational Sources

For a spherically symmetric gravitational source, the light speed distribution in the surrounding vacuum follows the following functional relationship:

$$c(r) = c\sqrt{1 - \frac{2GM}{(c^2 r)}} \qquad (6\text{-}1)$$

This function reveals that the relative light speed $c(r)$ forms a "light speed field" that decreases continuously from the outside inward. From the perspective of Vacuum Dynamics, this light speed field constitutes a variable-energy space with a continuous inward decrease in energy. The object within will spontaneously accelerate toward the lower energy space (the center of the gravitational source).

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6.2. Mathematical Derivation: From Light Speed Distribution to Gravitational Acceleration

Starting from the defining equation of Vacuum Dynamics, $g_m = -\nabla c^2$, we aim to verify the quantitative correlation between *gm* and the Newtonian gravitational acceleration g_N. In a spherically symmetric spacetime, this gradient can be simplified to the derivative with respect to the radial coordinate *r*, so the acceleration equation can also be expressed as:

$$g_m = -\frac{dc^2}{dr} \qquad \text{(6-2)}$$

Proceeding from the above equation, we first square both sides of the light speed distribution function *c*(*r*):

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

Subsequently, take the derivative of both sides of Equation (6-3) with respect to *r*:

$$\frac{dc^2}{dr} = \frac{2GM}{r^2} \qquad \text{(6-4)}$$

*Rearranging giv*es:

$$\frac{1}{2}\frac{dc^2}{dr} = \frac{GM}{r^2} \qquad \text{(6-5)}$$

Let $g_N = GM/\,r^2$, then we have:

$$g_N = \frac{1}{2} g_m \qquad \text{(6-6)}$$

Through the combination of the light speed distribution function and Vacuum Dynamics theory, the classical calculation formula for gravitational acceleration is derived above. This indicates that the physical cause of gravitational acceleration lies in the gravitational source modifying the light speed distribution in space. The light speed gradient endows objects with an acceleration independent of their mass, and the increased kinetic energy of the object originates from the decreased rest energy. This constitutes both the physical mechanism underlying the generation of gravitational acceleration and the formation of gravitational fields.

The force driving the object's accelerated motion stems from the object's internal spontaneous force rather than an externally applied force. Here, this spontaneous force is what we commonly refer to as "gravitation." Therefore, the gravitational phenomenon does not involve a direct mutual attraction between objects.

The aforementioned research demonstrates that the essence of gravitation is not an independent fundamental interaction, but a macroscopic manifestation of the vacuum electromagnetic background. Consequently, the attempt to "unify" gravitation and electromagnetism as two separate fundamental forces loses its significance. Nevertheless, the electromagnetic background of gravitation provides a novel theoretical approach to addressing the compatibility issue with quantum mechanics [6,7].

Physical Origin of the Factor-of-Two Relationship: As shown in Equation (6-6), why are g_m and g_N not directly equal but differ by a factor of two? The following explores the physical root of this discrepancy based on the law of conservation of mechanical energy.

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$$m g_N \Delta h = \frac{1}{2} m v^2 \qquad (6\text{-}7)$$

From this, the "kinetic energy-equivalent acceleration" a can be directly derived as:

$$a = \frac{\Delta h}{(\Delta t)^2} = 2 g_N \qquad (6\text{-}8)$$

i.e.:

$$g_N = \frac{1}{2} a \qquad (6\text{-}9)$$

It is evident that the factor-of-two relationship between the potential energy acceleration g_N and the kinetic energy-equivalent acceleration a is an inherent mathematical structure of energy conservation itself.

As previously illustrated, gm is derived from the kinetic energy term and is isomorphic to a. Comparing equations (6–6) and (6–9) shows that g_m is exactly equal to a. The above reveals the inevitability of the factor-of-two difference between g_N and gm from the perspective of energy conservation. This conclusion indicates that the gravitational theory of vacuum dynamics achieves a natural and seamless connection with Newtonian gravity at the theoretical level.

7. Conclusion

This paper establishes a logically consistent Vacuum Dynamics theory, whose core lies in demonstrating that "the light speed gradient can serve as a universal physical principle driving the spontaneous motion of matter." We reveal a complete dynamic chain from the light speed gradient to the rest energy difference, and further to the spontaneous force and its universal acceleration ($g_m = -\nabla c^2$). Moreover, we successfully interpret universal gravitation as a macroscopic manifestation of this principle under specific spacetime backgrounds ($g_N = -\frac{1}{2}\frac{dc^2}{dr}$). This not only provides a novel dynamic picture for understanding the essence of gravitation but, more importantly, theoretically predicts the feasibility of propellantless propulsion in vacuum.

The significance of this research lies in building a bridge connecting fundamental physics and aerospace applications. It indicates that the "gravitation" driving the motion of celestial bodies in the universe and the "thrust" on which humanity will rely to navigate propellantless thrusters in the future may originate from the same physical mechanism within the framework of Vacuum Dynamics. This insight will fundamentally transform the way we think about propulsion problems. We anticipate that this research will attract widespread attention from both academic and engineering communities, jointly promoting the transformation of this achievement from theory to reality.

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