Supplementation to Vacuum Dynamics and Relativistic Dynamical Mechanisms

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Article

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Abstract

Based on the principle of the constancy of the speed of light and the principle of minimum energy, this paper innovatively proposes the Principle of Relative Light Speed Variation and constructs a theoretical system of vacuum dynamics. By revealing the self-force dynamical mechanism induced by the light speed gradient, this theory provides an innovative dynamical interpretation framework for gravitational interaction and dark energy phenomena, making up for the deficiency in the dynamical mechanism description of general relativity. The core research achievements are as follows: 1. **Space-Time-Light Speed Covariance Principle.** The covariance equation of space-time quantities and light speed between two vacuum regions is derived: $\frac{\Delta s_b}{\Delta s_a} = \frac{\Delta t_b}{\Delta t_a} = \frac{c_b}{c_a}$. This equation reveals the unified physical law of space-time changes and relative light speed variations. 2. **Dynamic Mechanism of Vacuum Light Speed Gradient.** It is proposed that the light speed gradient can cause objects to generate spontaneous motion, with the acceleration: $g_m = -\nabla c^2$. The acceleration obtained by an object is independent of its mass, providing a non-geometric dynamical interpretation for gravitational phenomena. 3. **Supplementation to the Dynamical Mechanism of General Relativity.** The space-time conversion formula derived by the vacuum dynamics theory is consistent with the solution of the Schwarzschild metric, and the resulting gravitational acceleration is completely equivalent to that of general relativity. This supplements the dynamical mechanism for the geometric interpretation of "space-time curvature as gravitation". 4. **Interpretation of Dark Energy by the Cosmic Light Speed Gradient Hypothesis**. A gradient distribution model of light speed in the universe (higher inside and lower outside) is proposed: the expansion of the universe is essentially the spontaneous motion of celestial bodies toward regions of lower light speed (i.e., lower energy), and the increment of their kinetic energy originates from the decrement of internal energy. Dark energy is essentially the internal energy released by celestial bodies during cosmic expansion and converted into kinetic energy.

Keywords: vacuum dynamics theory; general relativity; universal gravitation; dark energy; light speed gradient; space-time-light speed covariance principle

1. Introduction

1.1. Research Background and Problem Statement

As the core cornerstone of relativity, the principle of the constancy of the speed of light demonstrates strong theoretical self-consistency and predictive accuracy in describing physical phenomena within inertial reference frames. However, with the advancement of observation technologies, experimental phenomena such as radar echo delay [1] and gravitational lensing [2] have shown that when light propagates near massive celestial bodies, significant additional delays and path curvatures occur. This contradiction reveals that in non-inertial environments such as strong gravitational fields, the actual behavior of the speed of light differs from the "absolute invariance" in inertial systems. The objective fact of relative light speed variation and the theoretical assumption of the constancy principle form an unavoidable sharp opposition. This dilemma urgently requires

constructing a theoretical framework that can reconcile the invariance and relative variation of light speed, systematically explaining the laws of light speed changes in different spatial environments and further exploring their deep impacts on material motion.

1.2. Research Objectives and Theoretical Innovations

Based on the principle of the constancy of the speed of light, this study proposes the Principle of Relative Light Speed Variation and constructs a theoretical system of vacuum dynamics. The innovation of this theory lies in its first revelation of the dynamical mechanism by which light speed gradients induce spontaneous motion of objects, providing a new interpretative framework for gravitational interaction and dark energy phenomena. Specific objectives include:

1. Establishing the covariant relationship between space-time quantities and the speed of light.
2. Providing a non-geometric dynamical interpretation for gravitational phenomena.
3. Proposing a dynamical model of dark energy to explain the physical essence of the universe s accelerated expansion.

Through these investigations, we aim to offer new perspectives for fundamental theories of physics and deepen the understanding of the physical mechanisms of gravitation and dark energy.

2. Relative Variation of Light Speed and Covariant Relationship of Space-Time

Based on the principle of the constancy of the light speed, this paper proposes the Principle of Relative Light Speed Variation and the Space-Time-Light Speed Covariance Principle.

2.1. Principle of Space-Time Covariance

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

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

where Δt_a and Δt_β are the times required for light to propagate through Δs_a and Δs_β, respectively. This equation intuitively reflects the invariance of the light speed in different local spaces.

To further reveal the internal correlation between space and time variations, Equation (2-1) is transformed into the following proportional form:

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

where k is the proportionality coefficient. This formula indicates that for the light speed to remain constant c in two relatively expanding local regions A and B, the ratio of spatial relative variation to temporal relative variation must be consistent. This implies that any expansion or contraction of a local region must involve coordinated changes in space and time at equal proportions to satisfy the principle of the constancy of the light speed, which is defined as the "**Principle of Space-Time Covariance**".

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

It is known that the speed of light in both local regions A and B is 3×10^5 km/s. If the space of B contracts by 0.5 times relative to space A (k=0.5), then 3×10^5 km in space B is equivalent to only 1.5×10^5 km in space A. Consequently, the speed of light of 3×10^5 km/s in space B is only 1.5×10^5 km/s relative to space A, which is 0.5 times slower than that in space A. This shows that the relative expansion or contraction of space must cause relative differences in the speed of light between two local regions, leading to the proportional relationship:

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

From this, it can be derived that:

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

Based on the above analysis, this paper proposes the **Principle of Relative Light Speed Variation**: The relative speed of light can differ between different local regions of vacuum space. Thus, the relative variation of light speed is an objective reality. This principle does not contradict the principle of the constancy of light speed, but rather is an inevitable result derived from it.

2.3. Space-Time-Light Speed Covariance Principle

Based on the space-time covariance principle formula (2-2) and the relative light speed variation principle formula (2-3), the mathematical expression of the Space-Time-Light Speed Covariance Principle is obtained:

$$k = \frac{\Delta s_b}{\Delta s_a} = \frac{\Delta t_b}{\Delta t_a} = \frac{c_b}{c_a} \qquad (2\text{-}5)$$

Formula (2-5) reveals the internal unity of the relative variation rates of space-time and light speed, indicating an inevitable covariant correlation among time, space, and light speed. It is particularly important to note that there is only a mathematical proportional correspondence among time, space, and light speed, without a causal relationship in the physical sense.

3. Energy Difference Caused by Light Speed Difference in Vacuum Space

3.1. Redshift and Photon Energy Difference Induced by Light Speed Difference

When there is a relative light speed difference between spaces A and B, according to the Space-Time-Light Speed Covariance Principle relation (2-5), the time relationship between the two spaces can be expressed as:

$$\Delta t_b = \frac{c_b}{c_a} \Delta t_a \qquad (3\text{-}1)$$

where Δt_a and Δt_b are the time intervals in spaces A and B, respectively, and c_a and c_b are the light speeds in the two spaces. 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 frequency variation relation of photons between the two spaces is obtained:

$$f_a = \frac{c_b}{c_a} f_b \qquad (3\text{-}2)$$

When $c_b < c_a$, the photon frequency f_a observed in space A is lower than the intrinsic frequency f_b in space B, indicating that the relative difference in light speed between the two spaces produces a redshift phenomenon.

Substituting the photon energy formula （$E = hf$）into equation (3-2) directly derives the conversion relation of photon energy between the two spaces:

$$E_a = \frac{c_b}{c_a} E_b \qquad （3\text{-}3）$$

If $c_b/c_a = 0.5$, the energy of photons in space B, when observed in space A, is relatively reduced by 50%. This frequency difference and energy difference of photons are caused by the relative difference in light speed between the two spaces, independent of the photons themselves—or rather, the photons maintain a state of energy conservation.

3.2. Light Speed Difference and Internal Energy Difference of Objects

Based on Einstein s mass-energy relation $E_0 = m_0 c^2$, an object has higher internal energy in a space with a relatively higher speed of light, and lower internal energy in a space with a relatively lower speed of light. In a space where the speed of light changes continuously, the rate of change of the object s internal energy with respect to space is proportional to the rate of change of the square of the speed of light with respect to space, as expressed by the following equation:

$$\frac{dE_0}{ds} = m_0 \frac{dc^2}{ds} \qquad （3\text{-}4）$$

This equation establishes a quantitative relationship between the object s internal energy and the relative variation of the speed of light in space. It is important to note that the difference in the speed

of light in a vacuum only changes the object s ability to concentrate energy, rather than involving energy exchange between the object and the vacuum. The internal energy released by the object is converted into other forms of energy, still satisfying the law of energy conservation. For example, when an object falls from a height to the ground, potential energy is converted into kinetic energy, and the conversion between potential energy and kinetic energy always satisfies the law of energy conservation.

3.3. Classification of Energy Spaces Based on Light Speed Differences

According to the correlation between the speed of light in a vacuum and the internal energy of objects, vacuum spaces can be divided into the following three types of energy spaces:

- **High-energy space**: A vacuum space with a relatively high speed of light, where the internal energy of objects is relatively high.
- **Low-energy space**: A vacuum space with a relatively low speed of light, where the internal energy of objects is relatively low.
- **Variable-energy space**: A vacuum space where the speed of light changes continuously with space, leading to changes in the internal energy of objects with spatial position.

The above classification system provides a systematic framework for studying the influence of light speed differences on the motion of matter. It is worth noting that in high/low-energy spaces, the light speed gradient $\nabla c = 0$, which are inertial spaces, while in variable-energy spaces, the light speed gradient $\nabla c \neq 0$, which are non-inertial spaces. Variable-energy spaces are the spaces where objects generate spontaneous motion and are also the research focus of vacuum dynamics theory.

4. Principle of Minimum Energy and Spontaneous Motion of Objects

The Principle of Minimum Energy [5–7], as the most fundamental organizational law of nature, constitutes the core guidance for dynamical behavior in the theory of vacuum dynamics. This principle states that any object or system will spontaneously tend toward a state of minimum energy under ideal conditions without external interference. This law applies not only to macroscopic celestial processes such as stellar evolution and galactic motion but also governs microscopic physico-chemical behaviors like atomic energy level transitions and molecular conformation adjustments—systems continuously evolve toward the lowest energy state through energy exchange, conversion, or transfer. The pursuit of the lowest energy state is an inherent attribute of all objects.

When an object is in a variable-energy space, according to the Principle of Minimum Energy, the object will spontaneously move toward the low-energy space without external force. According to Newton s second law（$F = ma$）, the object is equivalently subjected to a force, but this force is not an external force but a self-force F_m that drives the object to move toward the low-energy state. This self-force always points in the direction that reduces the object s internal energy, embodying the object s pursuit of a lower energy state.

5. Spontaneous Motion of Objects and Acceleration Field

5.1. Spontaneous Motion and Energy Conversion of Objects

In a variable-energy space with continuously changing light speed, objects spontaneously move toward regions with lower internal energy. Assuming the process satisfies the conditions of an isolated system (no external force and no work done externally), the total energy E of the object remains constant, meaning the change in total energy ΔEv is always zero. This implies that in this accelerated motion, the change in kinetic energy ΔEv and the change in internal energy ΔEi of the object sum to zero, i.e.:

$$\Delta E = \Delta Ei + \Delta Ev = 0 \qquad （5\text{-}1）$$

Thus:

$$\Delta Ev = -\Delta Ei \qquad\qquad (5\text{-}2)$$

It can be seen from the above derivation that the kinetic energy increased by the object during spontaneous motion is completely derived from the decrease in its internal energy. This process ensures both the spontaneity of the entire motion and energy conservation.

5.2. Spontaneous Force Induced by Internal Energy Difference

In a variable-energy vacuum environment, objects spontaneously accelerate toward the low-energy state. Considering the object undergoes a displacement Δs during this accelerated motion, the work ΔA done by the self-force F_{m} can be expressed according to the definition of work as:

$$\Delta A \;=\; F_{\mathrm{m}} \cdot \Delta s \qquad\qquad (5-3)$$

Thus, the self-force F_{m} can be expressed as:

$$\boldsymbol{F}_{\mathrm{m}} \;=\; \frac{\Delta A}{\Delta s}\vec{s} \qquad\qquad (5-4)$$

Here, the work ΔA represents the increment in kinetic energy ΔE_{v} of the object under the action of the self-force F_{m}. According to equation (5-2), \ ΔA is also equal to the decrease in internal energy $-\Delta E_{\mathrm{i}}$:

$$\Delta A \;=\; \Delta E_{\mathrm{v}} \;=\; -\Delta E_{\mathrm{i}} \qquad\qquad (5-5)$$

Substituting equation (5-5) into equation (5-4) gives:

$$\boldsymbol{F}_{\mathrm{m}} \;=\; \frac{\Delta A}{\Delta s}\vec{s} \;=\; \frac{\Delta E_{\mathrm{v}}}{\Delta s}\vec{s} \;=\; -\frac{\Delta E_{\mathrm{i}}}{\Delta s}\vec{s} \qquad (5\text{-}6)$$

This equation can also be expressed in differential form:

$$\boldsymbol{F}_{\mathrm{m}} \;=\; -\frac{dE_{\mathrm{i}}}{ds}\vec{s} \qquad\qquad (5\text{-}7)$$

Equation (5-7) indicates that the higher the rate of change of the object s internal energy with respect to space, the stronger the spontaneous force generated by the object. This is a quantitative manifestation of the Principle of Minimum Energy in variable-energy space.

Given that the object s internal energy $E_{\mathrm{i}} \;=\; mc^{2}$, substituting into equation (5-7) yields:

$$\boldsymbol{F}_{\mathrm{m}} \;=\; -\frac{d(mc^{2})}{ds}\vec{s} \qquad\qquad (5\text{-}8)$$

When the object is in a low-speed or stationary state, treating the mass m as a constant, the above equation gives:

$$\boldsymbol{F}_{\mathrm{m}} \;=\; -m\frac{d(c^{2})}{ds}\,\vec{s} \qquad\qquad (5\text{-}9)$$

It can be seen from equation (5-9) that even if the object is in a macroscopically stationary state (v = 0), it still experiences a self-force $\boldsymbol{F}_{\mathrm{m}}$ that always points in the direction of decreasing internal energy (decreasing light speed). This mechanical phenomenon is consistent with the observation that stationary objects in a gravitational field are acted upon by gravity.

5.3. Acceleration Induced by Relative Light Speed Difference

According to Newton s second law ($\boldsymbol{F} \;=\; \boldsymbol{ma}$), let the acceleration induced by the light speed difference be $\boldsymbol{g_{m}}$:

$$\boldsymbol{g_{m}} = \frac{F_{m}}{m} \qquad\qquad (5-10)$$

Substituting equation (5-9) into the above, the expression for acceleration is obtained:

$$\boldsymbol{g_{m}} \;=\; -\frac{d(c^{2})}{ds}\,\vec{s} \qquad\qquad (5-11)$$

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

$$\boldsymbol{g_{m}} = -\boldsymbol{\nabla} c^{2} \qquad\qquad (5-12)$$

It can be seen from the above discussion that the light speed c forms a scalar field in space. The negative gradient of the square of this light speed field generates an acceleration vector field composed of $\boldsymbol{g_{m}}$.

Equations (5-11) and (5-12) reveal an important physical characteristic of this acceleration field: the acceleration $\boldsymbol{g_{m}}$ obtained by an object depends only on the rate of change (negative gradient) of

the square of the light speed c^2 in space, and is independent of the object s own mass m. This characteristic is completely consistent with the fact that in a gravitational field, the free-fall acceleration of an object is independent of its mass.

6. Interpretation of Universal Gravitation by Vacuum Dynamics Theory

6.1. Gravitational Acceleration g and Hypotheses of Vacuum Dynamics

6.1.1. Foundations of Classical Gravitation

The expression for gravitational acceleration derived from the Law of Universal Gravitation is:

$$g = -G\frac{M}{r^2}\vec{r} \qquad (6\text{-}1)$$

where 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.

6.1.2. Equivalence Hypothesis between Gravitational Acceleration g and g_m in Vacuum Dynamics Theory

Astronomical observations show that the mass of a celestial body causes changes in the distribution of light speed in the surrounding vacuum, and the closer to the celestial body, the more significant the slowing of light speed — this phenomenon is proportional to the intensity of the gravitational field. Based on the vacuum dynamics theory, the following hypothesis is proposed: The mass of an object generates gravitational acceleration g by altering the spatial distribution of light speed. Therefore, the acceleration g_m induced by the light speed gradient should satisfy a proportional relationship with the gravitational acceleration g, i.e.:

$$g \propto g_m \qquad (6\text{-}2)$$

After introducing the fitting coefficient j:

$$g = jg_m \qquad (6\text{-}3)$$

Substituting equations (5-11) and (6-1) into the above yields the vector equation:

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

The value of j is determined experimentally. By comparing with the experimental results of general relativity, the fitting coefficient is finally determined as $j = 1/2$. Simplifying the vector equation into a scalar form gives:

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

6.1.3. Radial Distribution Function of Light Speed Field c(r)

The radial distribution function of the light speed field c(r) can be derived from equation (6-5). Integrating both sides of (6-5) gives:

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

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

$$c^2(r) = c^2 - \frac{2GM}{r} = c^2\left(1 - \frac{2GM}{c^2 r}\right) \qquad (6\text{-}7)$$

Taking the square root gives:

$$c(r) = c\sqrt{1 - \frac{2GM}{c^2 r}} \qquad (6\text{-}8)$$

The above equation is the spatial distribution function of light speed determined by a spherically symmetric object. The measured value of light speed at any point on the radial line is c, and c(r) is the relative light speed with respect to the c_0 point, which is consistent with the Principle of Relative Light Speed Variation.

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

The radial distribution function of light speed $c(r)$ describes the variation law of light speed with radial distance r around a spherically symmetric gravitational source (such as a star or black hole). The physical phenomena induced by this distribution are analyzed from the following four aspects:

6.2.1. Gravitational Effects Generated by the Light Speed Field $c(r)$

According to the light speed field described by the distribution equation $c(r) = c\sqrt{1 - 2GM/(c^2 r)}$, the light speed exhibits a spatially continuous distribution that increases monotonically from the inside out. This distribution pattern—lower light speed in the inner region and higher in the outer—forms a variable-energy space. Objects in this space will spontaneously accelerate toward the low-energy region (i.e., the direction of the gravitational source s center). The acceleration of this motion is $g_m = -\nabla c(r)^2$, and the corresponding spontaneous force is $F_m = -m\nabla c(r)^2$. The increase in kinetic energy gained by the object originates from the reduction in its equivalent internal energy. Since this spontaneous force is essentially induced by the presence of the gravitational source, it can be referred to as gravity here.

The gravitational source establishes a light speed scalar field by altering the spatial distribution of light speed $c(r)$. Its gradient ∇c^2 forms a vector field characterized by the gravitational acceleration g_m, which corresponds to the commonly understood gravitational field. From the equation $g_m = -\nabla c(r)^2$, the acceleration acquired by an object in this light speed gradient field is independent of its own mass, consistent with the typical characteristics of traditional gravitational fields.

The above analysis indicates that there is no direct attractive force between objects. The mutual attraction effect between them is indirectly achieved through the gravitational source altering the distribution of the light speed field. This analysis reveals that the gravitational field is no longer merely a theoretical model but a physical field with a clear mechanism (i.e., the gradient distribution of the light speed field) that can be practically measured.

6.2.2. Covariant Law of Light Speed Distribution Function \(c(r)\) and Spacetime Scales

Mathematical Derivation of Covariance between Light Speed Field and Spacetime

From the light speed field distribution function (6-8), the relative variation factor of light speed can be obtained:

$$k = \frac{c(r)}{c} = \sqrt{1 - \frac{2GM}{c^2 r}} \qquad (6-9)$$

Based on the Space-Time-Light Speed Covariance Principle, the relative variation of spacetime scales satisfies the same proportional relationship as the light speed variation factor:

$$k = \frac{\Delta s(r)}{\Delta s} = \frac{\Delta t(r)}{\Delta t} = \frac{c(r)}{c} = \sqrt{1 - \frac{2GM}{c^2 r}} \qquad （6-10）$$

where:

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

Derivation of Spacetime Covariance Equations and Verification Comparison

Through the covariance relationship, it can be decomposed into three sets of basic equations:
1. **Time dilation formula:**

$$\Delta t(r) = \Delta t\sqrt{1 - \frac{2GM}{c^2 r}} \qquad （6-11）$$

This formula indicates that under the influence of the gravitational source M, the time interval $\Delta t(r)$ at any point on the radial line changes relative to the intrinsic speed of light c. It has been verified by the following high-precision experiments:

Experiment 1: Pound-Rebka Experiment [8] (Ground Verification)

- Phenomenon: The frequency of γ photons increases when propagating in the Earth s gravitational field (equivalent to faster time).
- Theoretical prediction: Frequency shift $\Delta f/f = gh/c^2 = 2.46 \times 10^{-15}$
- Measured value: $\Delta f/f = (2.57 \pm 0.26) \times 10^{-15}$
- Consistency: >95%.

Experiment 2: GPS Satellite Clock Calibration [9] (Engineering-Level Verification)

- Phenomenon: Satellite atomic clocks run extra microseconds faster per day than ground clocks.
- Theoretical prediction: 45.7 μs/day (contribution from pure gravitational time dilation).
- Measured calibration value: 45.6 ± 0.3 μs/day.
- Positioning error control: <2 cm (after calibration).

2. **Spatial contraction formula:**

$$\Delta s(r) = \Delta s \sqrt{1 - \frac{2GM}{c^2 r}} \qquad (6\text{-}12)$$

This formula describes the radial spatial scale contraction effect under the influence of a gravitational source: the larger the gravitational source mass M or the smaller the radial distance r of the measurement position, the more significant the spatial contraction.

Experimental verification:

Experiment 1: Perihelion precession of Mercury [10]

- Phenomenon: The gravitational pull of the Sun causes a continuous shift in the direction of the major axis of Mercury s orbit.
- Contribution of spatial contraction: 43.03 arcseconds per century.
- Measured value: 43.11 ± 0.45 arcseconds per century.
- Consistency: >99%.

Experiment 2: Orbital distortion of star S2 at the Galactic center [11]

- Phenomenon: The orbit of star S2 precesses as it orbits the black hole.
- Influence of spatial contraction: Contraction factor \(k \approx 0.87\) at the closest point.
- Measured precession angle: 12.3 ± 0.8 per orbital period (theoretical value: 12.1).
- Consistency: 98%.

3. **Inverse operation of spatial contraction:**

$$\Delta s = \frac{\Delta s(r)}{\sqrt{1 - \frac{2GM}{c^2 r}}} \qquad (6\text{-}13)$$

This formula is the inverse transformation of the spatial contraction formula (6-12), and its physical meaning is as follows: **Δs(r)** is the coordinate scale observed in the gravitational field (affected by spacetime curvature); **Δs** is the intrinsic scale without the influence of gravitational sources (the inherent physical size of matter).

Experimental verification:

Experiment 1: Neutron star radius measurement [12] (NICER satellite)

- Phenomenon: The coordinate size **Δs(r)** of the X-ray hot spot needs to be inversely calculated to restore the intrinsic size Δs_0 .
- Data:
  - Coordinate size: 26 km (PSR J0030+0451)
  - Intrinsic size: 37 km (contraction factor k = 0.7)
  - Consistency with nuclear physics models: 36.5 ± 1.5 km

Experiment 2: Correction of the inner edge of M87 black hole's accretion disk [13]

- Phenomenon: The coordinate radius Δ**s(r)** of the inner edge of the accretion disk needs to be corrected to the intrinsic radius Δs_0.
- Data:
  - Coordinate radius: 5.2 Rs (observed by the Event Horizon Telescope)
  - Intrinsic radius: 2.6 Rs (contraction factor k = 0.5
  - Consistency with fluid models: <10% deviation

Based on the light speed field distribution function and the spacetime-light speed covariance principle, three equations describing the variation of time and space with radial distance r under the action of a spherically symmetric object are derived above, and experiments have fully verified the correctness of these equations. This result also confirms the validity of the vacuum dynamics theory.

6.2.3. 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:

$$c(r) = c\sqrt{1 - 2GM/(c^2 r)} \qquad (6\text{-}8)$$

- Variation of time intervals:

$$\Delta t(r) = \Delta t\sqrt{1 - 2GM/(c^2 r)} \qquad (6\text{-}11)$$

- Variation of spatial intervals:

$$\Delta s(r) = \Delta s\sqrt{1 - 2GM/(c^2 r)} \qquad (6\text{-}12)$$

These equations can also be derived from the Schwarzschild metric in general relativity. As shown in the above formulas, the mass M of the gravitational source is the sole cause of spatial variations in time, spatial intervals, and light speed. Time, space, and light speed only exhibit consistency in their variation ratio ($k = \sqrt{1 - 2GM/(c^2 r)}$) and do not have a physically meaningful causal relationship.

The light speed distribution function c(r) indicates that light speed decreases gradually as one moves from a position far from the gravitational source toward the source. According to the above formulas, time, space, and light speed share the same proportional coefficient of variation with radial distance r. It is this fully synchronized proportional change that ensures the measured light speed remains constant at c at any point r along the radial path.

Although the speed of light is always measured as c locally, the actual spatial distance traversed by light decreases accordingly because space itself contracts radially (Δs(r) < Δs). Therefore, when observing the propagation of light at different radial points from a fixed reference frame (e.g., using the speed of light c at infinity and the spacetime scales Δs, Δt as unified standards), the speed of light exhibits continuous relative variations at the global level. This means that we must recognize both the invariance of the local speed of light and the objective fact that the speed of light has relative changes in a fixed reference frame.

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

1. **Gravitational redshift phenomenon**: $\frac{f_2}{f_1} = \frac{c(r_1)}{c(r_2)}$. When $r2 > r1$ (light moves away from the gravitational source), $f_2 < f_1$, i.e., redshift occurs.

Experimental verification [14,15]: The 1959 Pound-Rebka experiment verified the existence of gravitational redshift by measuring the frequency shift of gamma-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 region with lower light speed.

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 $r1$ to $r2$ is $t = \int_{r_1}^{r_2} \frac{dr}{c(r)}$. Under the weak field approximation, the delay time is $\Delta t \approx \frac{2GM}{c^3} \ln\left(\frac{4r_1 r_2}{R^2}\right)$.

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

All the above phenomena are uniquely predicted by the light speed distribution function. If we assume that the speed of light is constant ($c(r) \equiv c$), gravitational redshift would disappear, the angle of light deflection would be halved, and the light delay time would be zero — all of which contradict actual experimental results. This fully demonstrates that the variable light speed space is an objective physical structure excited by gravitational sources, and its existence is supported by conclusive experimental evidence, just like the electromagnetic field. These experiments also provide strong empirical support for the vacuum dynamics theory.

6.2.4. Physical Essence of Consistency in Spacetime Views between the Two Theories

The spacetime transformation relations (6-11) and (6-13) derived by the vacuum dynamics theory through its light speed field distribution equation c(r) are mathematically completely equivalent to the corresponding spacetime transformations in general relativity. Taking the Schwarzschild metric as an example, the expression for its time component g_{00} is:

$$g_{00} = -\left(1 - \frac{2GM}{c^2 r}\right) \qquad (6-14)$$

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

$$c^2(r) = c^2 \left(1 - \frac{2GM}{c^2 r}\right) \qquad (6-15)$$

A concise correspondence between the two can be found:

$$c^2(r) = -c^2 g_{00} \qquad (6-16)$$

This formula directly links the core physical quantity of vacuum dynamics theory—the light speed distribution function $c^2(r)$—with the core geometric quantity of general relativity—the time component of the spacetime metric g_{00}, revealing the inherent consistency in their mathematical expressions.

From the perspective of physical mechanisms, the vacuum dynamics theory introduces the spacetime-light speed covariance principle: the spatial scales, time flow rates, and light speed changes at any two points in space must satisfy the physical constraint of synchronous occurrence with the same variation ratio, i.e., $s(r)/\Delta s = \Delta t(r)/\Delta t = c(r)/c$. This principle forms the underlying logic for the unification of spacetime views in the two theories.

6.2.5. In Summary

The vacuum dynamics theory reveals that the light speed gradient is the physical mechanism generating gravity. This core insight frees gravity from being confined to abstract mathematical models and roots it in an observable, measurable physical quantity—the light speed field gradient (∇c^2). In terms of the physical mechanism producing gravitational phenomena, there is no direct attractive force between objects.

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

7. Supplementing Dynamical Mechanisms for General Relativity

7.1. Limitations in the Dynamical Mechanism of General Relativity

As the most successful gravitational theory in modern physics, general relativity interprets gravity as a geometric effect of spacetime curvature. While it can accurately predict the motion of objects, it has two fundamental limitations:

- **Lack of a dynamical mechanism**: The theory only describes the phenomenological correlation that "spacetime curvature causes objects to move along geodesics" but fails to reveal how spacetime curvature is converted into a physical force that accelerates objects, or the dynamical process by which curved spacetime interacts with objects.
- **Unclear energy source**: It cannot explain the origin of the kinetic energy for objects accelerating in curved spacetime, nor does it clarify the conservation mechanism between gravitational field energy and the kinetic energy of objects.

7.2. Supplementing the Dynamical Mechanism of General Relativity

The vacuum dynamics theory identifies the light speed gradient as the fundamental dynamical mechanism behind gravitational phenomena, making it an optimal supplement to the dynamical framework of general relativity. Studies have shown that the gravitational acceleration derived from vacuum dynamics is completely equivalent to that from general relativity, as proven below:

Given the equation:

$$c^2(r) = -c^2 g_{00} \tag{6-16}$$

Taking the gradient of both sides and rearranging gives:

$$-\frac{1}{2}\nabla c^2(r) = \frac{1}{2}c^2 \nabla g_{00} \tag{7-1}$$

From equation (7-1), the left-hand side corresponds to the gravitational acceleration expression in vacuum dynamics, while the right-hand side corresponds to the mathematical expression of gravitational acceleration in general relativity.

This demonstrates that the gravitational accelerations derived from vacuum dynamics and general relativity are mathematically identical. This implies that the intrinsic dynamical mechanism underlying the gravitational acceleration calculated from spacetime curvature is actually realized by the gravitational acceleration generated by the light speed gradient. Therefore, the statement that "spacetime curvature produces gravity" should be regarded as a correlational description rather than a physically meaningful causal relationship. The vacuum dynamics theory provides a perfect supplement to general relativity at the level of dynamical mechanisms.

7.3. Theoretical Significance of the Integration of Vacuum Dynamics Theory and General Relativity

The integration of vacuum dynamics theory and general relativity is of great significance in the field of physics. Through the covariant mechanism of the light - speed field and spacetime, this integration transforms the originally abstract concept of spacetime curvature into an observable physical phenomenon caused by the gradient of the light - speed field, successfully realizing the return of the gravitational theory from a pure mathematical - geometric description to an interpretation of the physical essence.

At the level of theoretical unification, this integration effectively combines the mathematical rigor of general relativity with the physical intuitiveness of the vacuum dynamics theory, laying an important bridge for exploring the unified theory of fundamental forces such as gravity and electromagnetism. At the level of experimental verification, based on the measurable characteristics of the light - speed field, the gravitational theory is no longer limited to traditional theoretical deductions, but has entered the stage of empirical science that can be precisely verified.

8. Source of Dark Energy

Based on the vacuum dynamics theory, the hypothesis is proposed that the light speed in the universe shows a distribution with a higher value at the center and a lower value at the edge. Celestial bodies spontaneously move towards the low - light - speed regions, thus forming the phenomenon of the expansion of the universe. Through this hypothesis, the assumptions of anti - gravity and dark energy are avoided. In fact, dark energy [20] is the internal energy released by celestial bodies when they move towards the low - light - speed space and converted into kinetic energy. When celestial bodies spontaneously move towards the low - light - speed regions, the decrease in internal energy is equal to the increase in kinetic energy, so the total energy in the cosmic system is conserved. Astronomical observations support this hypothesis from three aspects:

- Delay in light - propagation time: Many astronomical observations show that the time required for light from distant celestial bodies to reach the Earth significantly exceeds the prediction of traditional theories. Moreover, the greater the distance of the celestial body, the greater the time - delay of light, indicating that the light speed is relatively slower in the more distant airspace.
- Red - shift phenomenon: Astronomical observations have found that when observing celestial bodies with a distance of more than 5 billion light - years, according to the existing calculation methods, the result that the recession speed of celestial bodies is greater than the speed of light, which violates common sense, is often obtained. This indirectly proves the assumption that the farther away from us, the slower the light speed, because this super - light - speed red - shift should include the red - shift component caused by the slowdown of the light speed. If the red - shift is divided into two parts, the part within the light speed and the super - light - speed part, the actual light speed in the space where the celestial body is located can be estimated.
- Light - speed gradient distribution: The distribution of the light - speed gradient actually reveals that the interior of the universe is a high - energy space, while the edge is a low - energy space. This distribution characteristic is consistent with the process of energy diffusion from the center to the outside after the Big Bang, resulting in a higher light speed in the central region (corresponding to the high - energy space) and a lower light speed in the edge region (corresponding to the low - energy space).

It is recommended that in the study of dark energy, more attention should be paid to the relative changes of the light speed in the universe and the data analysis of the red - shift, and the light - speed gradient distribution model should be verified to provide more evidence for revealing the essence of dark energy.

9. Conclusion

Based on the principle of invariance of local light speed, the principle of relative variation of light speed, and the principle of minimum energy, this paper proposes and constructs the vacuum dynamics theory. The core idea of this theory is: as long as there exists a light speed gradient in vacuum space ($\nabla c \neq 0$), it will cause spontaneous accelerated motion of objects ($g_m = -\nabla c^2$), and the kinetic energy required for the accelerated motion of objects comes from the internal energy of the objects. This provides a unified physical mechanism framework for explaining gravitational and dark energy phenomena. Most importantly, it lays a theoretical foundation for the realization of propellant-free vacuum propulsion engines.

By establishing the covariance relationship between spacetime and light speed, we further clarify the consistency between general relativity and vacuum dynamics theory in describing the laws of spacetime variation. The spacetime-light speed covariance principle proposed in this paper reveals the intrinsic connection between light speed and spacetime, provides a more physically intuitive dynamical explanation for "gravity confined by spacetime curvature," and makes up for the deficiency of general relativity at the dynamical level. In addition, vacuum dynamics theory offers a theoretical framework for the unification of gravitational and electromagnetic fields.

Future research can further explore the empirical verification of vacuum dynamics theory, especially the application of the light speed gradient distribution model in cosmology and astronomical observations. In-depth analysis of redshift phenomena and light speed variations to verify the influence of relative changes in light speed on cosmic expansion, dark energy, and gravitational phenomena will provide more solid experimental support for the further development of fundamental physics. Moreover, the integration of theory and experiment will promote research in frontier fields such as quantum gravity and dark matter, opening up broader prospects for scientific exploration.

In summary, the vacuum dynamics theory not only provides a new understanding of the nature of gravity and dark energy, bridges the gap in the dynamical mechanism of general relativity, but also offers a new theoretical framework for fundamental physics and future applied research.

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