Relative Spacetime Scale and Absolute Spacetime Background

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Abstract

Based on the essential definitions of standard clock and standard ruler in physics and Einstein' s theory of relativity, this paper discusses the physical conception of spacetime from the perspective of natural philosophy. It proposes that on the basis of the existing concept of spacetime scale, a clearer distinction should be made between spacetime scale and spacetime background. According to the actual logic of Einstein' s relativity, it can be understood as follows: what satisfies relativistic variation is the spacetime scale, which is artificially defined based on intrinsic physical events occurring or existing in material entities, whereas the spacetime background, as the essential foundation and reference background for reflecting changes in the length or magnitude of spacetime scales, should be absolute. The length scale of spatial measurement should essentially be understood as the length of a segment intercepted on the absolute background of space by intrinsic physical events. Finally, based on this spacetime conception, the particle dynamics equations within the framework of classical mechanics are explored, and a new form of particle dynamics equations is naturally derived. The new dynamics equations can be directly applied to any actual non-rotating reference frame (relative to the absolute background of the universe). Moreover, the essence of inertial force is precisely the real force acting on the reference object. The essence of this reformulation of classical particle dynamics is to rectify a theoretical defect existing in the traditional system of Newton' s second law. However, perhaps more importantly, the new particle dynamics equations, which possess obvious formal superiority, in turn strongly suggest the absoluteness of the spacetime background. The paper concludes by exploring the physical effects of gravity on spacetime scales, in conjunction with the geometrization idea of gravity in general relativity.

Full Text

Relativistic Spacetime Based On Absolute Background

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Abstract

This paper begins by examining the most fundamental conceptual framework of spacetime at the level of natural philosophy. We propose that the concept of spacetime should be subdivided into two distinct levels: the *scale* of spacetime and the *background* of spacetime. The spacetime scale consists of the unit time and unit length artificially defined according to inherent physical phenomena occurring within specific material entities. Since the definition of scale depends on physical phenomena in concrete matter, it naturally becomes subject to various interactions and can thus accommodate the changes predicted by both special and general relativity. The spacetime background, serving as the essential foundation and reference for changes in the length or magnitude of the spacetime scale, should be absolute. In particular, the spatial background can be understood as the void or vacuum that remains after removing all matter. Since it contains no matter in any form, it cannot participate in any specific interactions, making the existence of an absolute background in the universe entirely natural. Consequently, the length scale of space (or time) should be understood essentially as the length of a line segment cut from the absolute background of space (or time) by the physical phenomenon that defines the scale.

Based on this foundational conceptual architecture of spacetime, we can uniquely and naturally derive the correct new particle dynamics equation within the framework of classical mechanics. In special relativity, the absolute background aligns with the notion that "events" have objectively unique and determined positions in spacetime; thus, special relativity implicitly presupposes or permits an absolute background. In general relativity, since the nature of inertial forces is interpreted as real forces acting on reference objects, we propose abandoning Einstein's equivalence principle and the principle of general relativity, and suggest modifying the theory of observation by discarding the concepts of standard clocks and tetrad theory. While retaining Einstein's gravitational field equations as the correct mathematical formulation for the geometrization of gravity, we propose that the spacetime coordinate scale in the metric (i.e., the length of unit spacetime intervals) should be understood as being replicated throughout all spacetime according to the observer's own clock and ruler. Consequently, the gravitational redshift experiments in the solar system can be successfully reinterpreted, while the cosmological metric should include an additional factor $b(t)$ in the time component, reflecting that although the universe's average gravitational field potential energy is uniform in space, it gradually increases along the temporal dimension with expansion. This introduces gravitational redshift physics when Earth-based observers analyze supernova spectral signals, and qualitative analysis ultimately suggests that even if current observations are correct, the introduction of dark energy may still be avoidable.

Keywords: Spacetime Physical Picture, Absolute Background, Cosmological Metric

1 Introduction

The current mainstream theories regarding the physical picture of spacetime are Einstein' s special and general relativity. Special relativity has achieved remarkable success in nearly all tests of its predictions and corollaries [?], particularly with quantum field theory built upon it achieving unprecedented precision, indicating that the core logic of special relativity is unshakable. Einstein' s general relativity is a spacetime theory of gravitation, with its most widely accepted tests to date being the three classical verification experiments under the static, spherically symmetric Schwarzschild metric in the solar system [?]. Therefore, the successful explanation of actual observational results based on the static, spherically symmetric Schwarzschild metric serves as a "touchstone" that any possible physical picture of spacetime must satisfy. Evidently, the physical picture of spacetime forms the foundation of almost all modern physical theories and has achieved great success. Any modification at this level would have far-reaching consequences. Consequently, the fine-tuning of the spacetime physical picture proposed in this paper must begin by providing a conceptual architecture from the most basic natural philosophy, followed by enriching the understanding of the spacetime physical image according to the core logic inherent in each relevant major physical theory.

The paper is organized as follows: Section 1 is the introduction. Section 2 presents the basic conceptual framework of spacetime entirely from naturalness and logical considerations at the most fundamental level of natural philosophy. Section 3 demonstrates, through logical deduction of the correct new particle dynamics equation, that the existence of an absolute spacetime background is an essential foundation for natural and reasonable derivation. Section 4 reviews special relativity, showing that while Lorentz coordinate transformations represent relative transformations between spacetime scales, the objective existence of unique, determined positions for events in spacetime essentially requires an absolute background. Section 5 reconstructs the physical picture of gravitational geometrization and reinterprets solar system gravitational redshift experiments. Section 6 proposes a more universal modification to the standard cosmological metric based on the fine-tuned spacetime physical picture, thereby salvaging the contribution of gravitational redshift effects in cosmological observations, deriving the corresponding cosmological dynamical equations, and discussing the essence of the cosmic acceleration problem. Section 7 provides a summary.

2 Conceptual Framework of Spacetime at the Natural Philosophy Level

First, from the basic requirements of logic, the relative and the absolute constitute two sides of a dialectical unity, complementing each other while being mutually opposed and impossible to exist independently. Any concept of relative change in time, relative unevenness or non-flatness in space, must necessarily refer to a more fundamental absolute reference background. Taking intuitive space as an example, if the infinite three-dimensional spatial background serving as the foundation for all things in the universe is regarded as the deepest-level background, it is naturally considered absolute, uniform, and flat by definition. For once the background itself possesses concepts of relative change, non-flatness, or non-uniformity, it would require reference to an even more fundamental background to make such assertions. We have already established the infinite three-dimensional space itself as the most fundamental background in our physical picture. Therefore, we can state that the three-dimensional infinite space serving as the universal background is absolute, uniform, and flat. While current discussions of cosmic creation are numerous [**?**, **?**], it must be clarified that the so-called created universe refers only to our observable universe, or the universe composed of surrounding concrete matter, and should not include the spacetime background serving as the foundation for all things in the universe. For if cosmic creation truly occurred from absolute nothingness, the preconditions for such creation would be non-existent—in other words, there would be no conditions at all. Moreover, since our current universe could be created, new universes could be created anytime, anywhere.

Second, from the most fundamental level of natural philosophy, spacetime serves as the most basic core concept in modern physical theory, touching upon the essence of all fundamental interactions. If the concept of relative change in spacetime scale emerges, then according to the basic principle of dialectical unity, we must distinguish between the relative and the absolute within the concept of spacetime. This paper designates the unit time and unit space defined in a reference coordinate system as the *scale* of spacetime. For instance, the precise definition of the second by the International Committee for Weights and Measures is based on the periodic stability of radiation emitted during transitions between two hyperfine levels of a stationary cesium-133 atom at absolute zero temperature and zero magnetic field [**?**]. Thus, the spacetime scale is fundamentally the length or span of the basic unit of spacetime defined according to inherent physical phenomena in concrete objects, and therefore does not represent spacetime in its entirety. Consequently, the concept of spacetime should be subdivided into two levels: the scale of spacetime and the background of spacetime.

The spacetime scale is the unit time and unit length artificially defined according to inherent physical phenomena occurring or existing in specific material entities. Because the definition of scale depends on physical phenomena in concrete matter, it naturally becomes subject to various interactions and can thus accommodate the changes predicted by both special and general relativity. The spacetime background, serving as the essential foundation and reference for changes in the length or magnitude of the spacetime scale, should be absolute. Taking intuitive space as an example, the spatial background can be understood as the void or vacuum after removing all matter. Since it contains no matter, it cannot participate in any specific interactions, making the existence of an absolute spatial background in the universe entirely natural. Consequently, the length scale of space (or time) can naturally be understood as the length of a line segment cut from the absolute background of space (or time) by the physical phenomenon that defines the scale. Specifically, a change in spatial scale—that is, a change in the standard unit of length—corresponds to a change in the length cut out from the spatial background by the physical phenomenon defining the unit "meter." Similarly, a change in temporal scale corresponds to a change in the span cut out from the temporal background by the physical phenomenon defining the "second." Whether such scale changes represent physical, intrinsic changes or observational effects is determined by the physical picture integrated with experimental verification in each physical theory.

Finally, the spacetime scale and spacetime background constitute two dialectically unified aspects of spacetime, not two separate spacetimes. The background is the fundamental substrate for the existence of objective things, not containing the things themselves, yet the changes of these things must occur within this background to be real. On this basis, the spatial background serves as the (reference) background for changes in position of all material entities in the universe, while the temporal background serves as the (reference) background for changes in state of all material entities.

Mathematically, the magnitude of the spacetime scale manifests as the length of the segment cut from the spacetime background by a proper physical event interval. Since segments have varying lengths, spacetime scales have varying magnitudes. Therefore, the magnitude of the temporal scale can be represented by the length $\Delta\tau$ cut from the temporal background manifold by the proper physical event interval used to define the temporal scale. In principle, clock and ruler readings are measured according to the number of unit proper physical event intervals elapsed, and thus do not directly contain information about the spacetime scale. Because any physical event has an objective position in the spacetime background of the universe, only when both parties being compared take the same two objective positions in the spacetime background can the readings of different clocks and rulers be compared to determine changes in spacetime scale. The reading of a proper clock is the value typically recorded by people, which can be represented by Δs. Thus, the physical concepts of proper clock reading Δs and the length $\Delta\tau$ it cuts in the temporal background manifold can be completely distinguished. Typically, Δs and $\Delta\tau$ appearing in spacetime invariant intervals represent clock and ruler readings.

3 Absolute Background as the Strongest Hint and Minimal Requirement for Deriving New Particle Dynamics Equations

Within the framework of classical mechanics, the traditional dynamical equation is Newton' s second law. However, theoretically Newton' s second law only holds in inertial frames; when applied in non-inertial frames, inertial forces must be added, with their magnitude depending on the relative acceleration between the non-inertial and inertial frames. Thus, classical dynamics is thoroughly built upon the concept of inertial frames [**?**, **?**]. Yet a well-known fact is that no strict inertial frame can be found in practical applications, which is clearly unsatisfactory [**?**, **?**]. Additionally, in practice, the particle dynamics law that is deeply ingrained and highly successful is actually an empirical law, not entirely equivalent to the theoretical Newton' s second law. This is because Newton' s second law strictly applies only to inertial frames, yet the actual reference frames used in practice are never strictly inertial! Moreover, a complete accounting of all forces acting on a particle has never truly been achieved. Therefore, understanding the subtle distinction between Newton' s second law and the widely tested empirical law is key to comprehending the physical significance of the new particle dynamics equation derived below.

In fact, the current theoretical form of Newton' s second law exhibits formal causal asymmetry. To see this clearly, let us assume Newton' s second law holds in some actual reference frame O. According to its current form, Newton' s second law should be expressed as $\vec{F}_{p\to O} = m_p\vec{a}_{p\to O}$, where the left side represents the total force on the object p being studied, depending only on p; the theoretical definition of force must be a complete accounting of all forces, otherwise when applying the theoretical formula to specific problems, one would not know which forces to include and which to exclude. The right side contains the acceleration $\vec{a}_{p\to O}$ of object p relative to the reference frame, i.e., the acceleration relative to the reference object fixed in frame O, which depends on both the studied object p and the reference object o. If force is considered the cause and acceleration effect the result, and temporarily ignoring specific details of force and acceleration, using arbitrary moving objects as formal variables, then formally the logic shows: $\vec{F}_{p\to O} \Leftrightarrow \vec{a}_{p\to O} \Leftrightarrow \vec{a}_{p\to o}$. Note that the choices of the object under examination p and the reference object o are completely independent; therefore, Newton' s second law exhibits formal causal asymmetry and inconsistency. This is precisely why Newton' s second law theoretically holds only in inertial frames, while no strict inertial frame can be found in practice.

Since reference frames must be used in applying dynamics, the determination of the acceleration of the object under examination is directly related to the motion of the chosen reference frame. As a causal correspondence, there is no reason for the reference frame' s forces to be absent. In fact, the physics of a reference frame that does not rotate relative to the cosmic spatial background can be attributed to the reference object defining the frame' s origin. Therefore, the forces on the reference frame can be fully implemented in the causal relationship of dynamics based on the forces acting on the reference object.

Can a satisfactory particle dynamics equation be obtained within the framework of classical mechanics? The key clue lies in the symmetry and consistency of causality on both sides of the dynamical equation. First, we accept the empirical law directly indicated by numerous classical mechanics experiments. In Newtonian mechanics, what is directly summarized from classical mechanics experiments and serves as the basis for determining formulas for common forces has never been Newton' s second law, because inertial frames have never been found, and the complete accounting of all forces required by Newton' s second law has never truly been achieved. The true empirical law is the difference equation expressing causality: on the basis of a previous mechanical state, the newly added force $\Delta\vec{F}$ experienced by an object and the resulting new relative acceleration $\Delta\vec{a}$ satisfy the causal relationship:

$$\Delta\vec{F} = m\Delta\vec{a}$$

Essentially, from the perspective of the statistical source of forces, the direct empirical law can only be a difference relation, not an integral relation. Formulas for common forces and determinations of object mass should be based on this equation. On this foundation, we logically deduce to find a new particle dynamics equation.

However, for empirical laws to be elevated to theoretical formulas, the force term in the theoretical formula must account for all forces on the particle. If this were not the case, one would not know which forces to consider when applying the formula to new situations. Therefore, the theoretical particle dynamics equation must handle all forces on the particle while remaining a causal theory (based on the difference relation, the differential causal relation can be expressed as $d\vec{F} = md\vec{a}$). Then, according to the causal consistency condition in particle dynamics, what should the effect corresponding to the total force on a particle from the entire universe be? The total force on a particle should be objective and not vary with the choice of reference frame, since the choice of reference frame involves arbitrary observer consciousness. Consequently, the corresponding effect must also be objective and independent of any reference frame. A completely objective acceleration of a particle can only be expressed as acceleration in the cosmic spatial background:

$$\vec{F}_p = m_p\ddot{\vec{\Omega}}_p \quad (4)$$

Here, the cosmic spatial background refers to the blank space or vacuum left in the universe after removing all evolvable things. The objectivity here means only that it is independent of any human-made choices. The position of a particle in the cosmic spatial background is inherently objective because no reference frame has been artificially introduced. The letter $\vec{\Omega}_p$ is specifically used to denote the objective position of particle p in the cosmic spatial background (note: the length of fundamental spacetime units, which we call spacetime scale, should be defined by the observer!). This is entirely similar to the concept of "events" in special relativity. At any moment, the objective position of any particle constitutes an event. Likewise, in special relativity, any event itself is assumed to have an objective position in the spacetime background, allowing the coordinate values of the same event to be related across different inertial reference frames. At the very least, the fact that any particle has an objective position in the cosmic spatial background at any moment is a necessary, though not sufficient, component of Newton' s absolute spacetime concept.

Digging deeper, the fact that a particle or event has an objective position in the cosmic spatial background strongly suggests that the cosmic spatial background is absolute. To be compatible with relativistic physics experiments, the extent of absolute concepts must be minimized. The concept of spacetime can be further divided into spacetime background and spacetime scale. The spacetime scale is essentially the length of the fundamental unit of spacetime, defined by the observer according to inherent physical phenomena in the natural material world, and therefore can be relative and subject to various interactions. However, the background reflecting the length of the spacetime scale must be absolute, because the spacetime background itself is not specific matter and no interaction can act upon it. Thus, logical deduction here indicates the minimal requirement: only the cosmic spatial background is absolute.

Although the position of any particle in the spatial background can be truly perceived, the objective position of a particle in the spatial background cannot be directly measured. What we can actually measure is the difference between two objective positions, such as between two objects p and o, which objectively constitutes a mathematical:

$$\vec{r}_{p-o} = \vec{\Omega}_p - \vec{\Omega}_o \quad (5)$$

All objects in the universe should be equivalent under the most fundamental dynamical laws. Both the arbitrary object under study p and the actual reference object o satisfy the same fundamental dynamics. Therefore, for the reference object o, its dynamics should also satisfy:

$$m_o\ddot{\vec{\Omega}}_o = \vec{F}_o \quad (6)$$

Here, the spacetime scale can be regarded as a strictly uniform scale randomly defined by the observer at the outset, which can naturally be defined by the inherent physical phenomena on the reference object after it is selected. So far, only one reference object o has been introduced (note: in this paper, reference frames are always marked with uppercase letters, reference objects with lowercase letters; e.g., reference frame O denotes the frame with reference object o as its origin). Therefore, the transformation law between spacetime scales of different reference frames has not yet been involved. The essence of choosing a reference frame is to enable relative measurement of motion; as a causal correspondence, forces naturally also have relativity. The reference object o can usually correspond naturally to the origin of the reference frame, thereby establishing a reference frame that does not rotate relative to the absolute background of cosmic space. Finally, simplifying (the right side can be viewed as relative force statistics) yields:

$$m_p\ddot{\vec{r}}_{p-o} = \vec{F}_p - \vec{F}_o \quad (7)$$

Thus, we have obtained a new form of particle dynamics equation within the framework of classical mechanics. The correctness of this equation within classical mechanics and its comparison with mechanical empirical laws have been thoroughly and repeatedly verified [**?**]. More importantly, this new particle dynamics equation formally satisfies the requirement of causal consistency, making the physical picture of classical dynamics more natural and concise [**?**]. From a practical standpoint, direct application of equation (6) no longer depends on the concept of inertial frames. For any actual reference frame that does not rotate relative to the cosmic background, the essence of inertial forces is the real force acting on the reference object, which needs to be subtracted in the relative force statistics.

The correctness of the new dynamics equation (7) has been strictly verified both theoretically and practically within the framework of classical mechanics [**?**]. Tracing this new dynamics equation to its physical roots, we find that the definitive nature of the causal symmetric form of the new particle dynamics equation in classical mechanics strongly suggests the existence of an absolute spacetime background. Notably, equation (7) can be simply transformed to obtain $m_p\ddot{\vec{r}}_{p-o} = \vec{F}_p - \vec{F}_o$, which compared to theoretical Newton' s second law, contains exactly one additional term: $-\vec{F}_o$, with all other forms and physical meanings being identical. Although this additional term is interpreted as an inertial force, compared to Newton' s second law, this is not a small, negligible correction, nor is it equivalent to the correction introduced when a particle moves from low to high speed, but rather a correction introducing an entire term. Through the causal consistency condition, it powerfully reflects the objective existence of the absolute background of cosmic space.

4 Absolute Background as the Implicit Condition for Events Having Objective Unique Positions in Spacetime

First, given the successful verification of special relativity in all aspects, it is appropriate to accept and retain its core logical framework. However, careful examination of special relativity' s axiomatic system reveals that it actually denies only the absoluteness of time measurement and the absoluteness of space measurement. As mentioned later, this is essentially only a denial of the absoluteness of spacetime scale.

Second, in the logical deduction of special relativity, all events, regardless of transformations between inertial frames, are assumed to have an objective, uniquely determined position in space [**?**]. Otherwise, the Lorentz coordinate transformation formulas between different inertial frames could not be obtained. This objective position can essentially be regarded as the reflection of the event' s occurrence point in the spatial background of the universe.

Therefore, when deriving the relationship between coordinate values of events in different inertial frames in special relativity, the assumption that events have objective positions in spacetime is actually relied upon. Otherwise, how could different inertial frames identify the same event? Thus, special relativity internally permits and presupposes the existence of an absolute spacetime background.

5 Physical Picture of Gravitational Geometrization and Reinterpretation of Solar System Gravitational Redshift

According to the new particle dynamics equation (8), the essence of inertial forces is revealed as $\vec{f}_{\text{inertial}} = -\frac{m_p}{m_o}\vec{F}_o$. Since the puzzle of inertial forces originates from the formal system of Newton' s second law, the cleanest approach to fundamentally explain the nature of inertial forces is to find a completely equivalent physical correspondence or replacement within the exact same framework; the most thorough approach to fundamentally eliminate the concept of inertial forces is to completely remove the inertial force problem within the original framework. The logical explanation of inertial forces above is achieved within the original classical mechanics framework, making it completely reasonable and valid. This explanation (9) shows that the essence of inertial forces is the real force on the reference object o, after mass-weighted averaging, which can be gravitational or other common non-gravitational interaction forces. Crucially, this force is not applied to the studied object but to the reference object. This revelation of the nature of inertial forces physically invalidates Einstein' s (medium-strong) equivalence principle.

Einstein' s equivalence principle is the greatest basis for his principle of general relativity. The invalidation of Einstein' s (medium-strong) equivalence principle essentially means that the principle of general relativity has no feasible roadmap in physics. On the other hand, from a mathematical analysis, it is well known that for a physically rotating rigid body reference frame, determining all kinematic degrees of freedom requires at least four points on different faces of the rigid body. Referring to the successful experience of reformulating the particle dynamics equation, constructing dynamical equations must satisfy the law of causal correspondence and consistency. If a physically rotating reference frame is chosen, the dynamical equation must theoretically incorporate the force and motion descriptions of at least four reference particles while maintaining a simple form. This has obviously never been naturally achieved. Therefore, the principle of general relativity faces an insurmountable gap mathematically.

In terms of experimental verification, the widely accepted solar system gravitational verification experiments mainly test the static Schwarzschild metric and do not truly involve transformations of arbitrary reference frames or physical situations of free-fall in gravitational fields. Therefore, this paper proposes modifying the theoretical framework of gravitational geometrization as follows:

1. **Abandon Einstein' s (medium-strong) equivalence principle**, eliminating the concept of local inertial frames and the definition of standard clocks by line element. In standard general relativity, the local inertial frame at any point in a gravitational field is the instantaneously co-moving free-fall frame. Since acceleration has no time dilation effect, according to the essential explanation of inertial forces, a naturally falling reference frame, even locally, cannot be equivalent to an inertial frame without a gravitational field in the spacetime metric. The correct gravitational geometrization should be based on the spacetime scale defined by the observer' s own clock and ruler, first hypothetically replicated throughout all spacetime, and then using this as the background. The difference between the local spacetime scale and the observer' s spacetime scale constitutes the curvature of the spacetime metric, which is the geometrization of gravity based on spacetime scale. Therefore, the coordinates in the spacetime metric have physical meaning and are directly related to the observer' s physics.

2. **The concept of spacetime is subdivided into two levels**: spacetime scale and spacetime background. What obeys the theory of gravitational geometrization is the spacetime scale, while the spacetime background is absolute. With the spacetime background as a reference, the rate of clock ticking becomes meaningful. The difference between local clocks and rulers in a gravitational field and the observer' s clock and ruler hypothetically replicated throughout the spacetime background reflects the degree of spacetime curvature.

3. **Abandon the principle of general relativity**, eliminating the observer' s tetrad theory and the assumption that observables must be general coordinate invariants. A natural and reasonable observation theory for gravitational geometrization directly extends from special relativity' s observation theory, based on coordinates and metric. In the new observation theory, the physics of the observer and reference frame should be fully incorporated into the metric of gravitational geometrization. Combining the idea of gravitational geometrization [**?**] with the basic physical picture based on spacetime scale + spacetime background [**?**], there exists a difference between the local spacetime scale defined by local proper event intervals in a gravitational field and the observer' s spacetime scale defined uniformly by the observer' s proper event intervals and replicated throughout spacetime. Therefore, the physical picture of gravitational geometrization leading to the spacetime metric should be: first, choose a non-rotating reference frame to determine the scope of relative gravitational statistics; second, within this scope, establish a strictly uniform coordinate system

with the reference origin as the coordinate origin; the spacetime coordinate scale is defined and replicated throughout the statistically affected spacetime according to the observer' s own measuring clock and ruler; finally, using this as the background reference, determine the degree of spacetime curvature by comparing local clocks and rulers with the observer' s spacetime coordinate scale as the background. According to this principle, the gravitational redshift effect in the solar system can be naturally and rigorously explained [**?**].

4. **Because solar system gravitational tests have achieved remarkable success, retain Einstein's gravitational field equations as the correct mathematical formulation for gravitational geometrization**. As for the relativity principle of Einstein' s field equations, it should fully refer to the extension of the relativity principle in particle dynamics, determining the scope of the relativity principle based on the true physics of the reference frame in the process of gravitational geometrization under the premise of causal consistency. Therefore, according to the law of causal correspondence and consistency, spacetime curvature geometric quantities and the energy-momentum tensor have a linear relationship, with the energy-momentum tensor as the cause and spacetime curvature as the effect. Different reference frames, their velocities and positions can affect calculations of the energy-momentum tensor, but the tensor is also covariant, thus not affecting the validity of Einstein' s gravitational field equations for gravitational geometrization. As for the translational acceleration of the reference frame, the passive view of reference frame acceleration is equivalent to the active view of matter acceleration. According to the mathematical definition of the energy-momentum tensor, reference frame acceleration has no effect on it. For spacetime geometric quantities, since an instantaneously jumpable acceleration cannot affect the curvature of the entire spacetime, in principle the instantaneous acceleration of the reference frame also does not affect the description of spacetime geometry. High-energy physics experiments have already provided evidence that the proper lifetime of a negatively charged muon is independent of its acceleration. In solar system surface gravitational redshift experiments, although atoms on the solar surface are in a constant gravitational field, their own accelerations are actually ever-changing, yet we still observe a definite redshift value, which also corroborates that acceleration is unrelated to time dilation.

Regarding forces, non-gravitational interaction forces do not affect gravitational geometrization, but gravitational interaction forces change the spacetime scale of the observer at the origin of the reference frame. Therefore, according to the causal consistency requirement of gravitational geometrization, we must always replicate the observer' s own measuring ruler and clock (with zero gravity equivalent to infinity) throughout all spacetime as the background for gravitational geometrization. For rotating reference frames, according to the definition of the energy-momentum tensor, the four-velocity of matter within it is a spatial vector, and spatial rotation changes the description of four-velocity, so rotating reference frames change the description of the energy-momentum tensor. Spacetime geometric quantities are also significantly affected, but covariance of the changes cannot be guaranteed. In summary, Einstein' s gravitational field equations as the mathematical formula for gravitational geometrization satisfy the relativity principle for reference frames with arbitrary translational acceleration—a moderate relativity principle.

To further test the physical picture of gravitational geometrization proposed in this paper, we next attempt to reinterpret the clock retardation effect of solar system gravity.

Given the case where the observer is at infinite distance from the Sun, the Schwarzschild metric after gravitational geometrization of the solar system satisfies [?, ?]:

$$ds^2 = -\left(1 - \frac{2GM}{r}\right) dt^2 + \left(1 - \frac{2GM}{r}\right)^{-1} dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2)$$

In this equation, the unit scale of dt and dr is defined by the observer' s own measuring clock and ruler. In other words, the observer' s own measuring clock and ruler are extensively replicated throughout the solar system. The so-called clock retardation is reflected as the difference between the reading of the local clock $\Delta\tau$ and the reading of the clock at infinity Δt on the same temporal background segment $\Delta\tau_0$. Clearly, at the solar surface, $\Delta\tau = \sqrt{1 - \frac{2GM}{r_\odot}}\,\Delta t < \Delta t$. Therefore, on the same temporal background segment, the reading of a clock at the solar surface defined by proper event counting is smaller than that of an observer' s clock at infinity. In other words, clocks at the solar surface run slower than those of an observer at infinity.

In the Schwarzschild metric, coordinate time t should be considered unchanged before and after gravitational geometrization—a strictly uniform mathematical clock that can be replicated throughout spacetime by the observer' s clock [?], thus called the observation clock. For two events occurring at the same spatial coordinate point, the difference between the time interval measured by the local clock and that measured by the observation clock reflects spacetime curvature. Regarding the gravitational redshift effect of light signals in the solar system, strictly speaking, it should be calculated in conjunction with the actual propagation process.

Because the solar system' s gravitational field is vacuum and spherically symmetric, its metric is static, i.e., independent of time t. Suppose there are two spatial points, one at r_1 and another at r_2, with a light signal propagating from r_1 to r_2. Its wavefront is emitted at coordinate time t_1 at r_1 and arrives at r_2 at coordinate time t_2. Therefore, the interval measured by the coordinate clock (i.e., observation clock) is $\delta t = t_2 - t_1$. Similarly, for the transmission of the next wavefront with phase difference, the interval measured by the coordinate clock can be expressed as $\delta t' = t'_2 - t'_1$. Since the solar system' s gravitational field is static and spherically symmetric, it is reasonable to consider that both experience equal coordinate time intervals: $\delta t' = \delta t$ (11). This equality shows that under a static spacetime metric, a light signal during propagation has the same period and frequency at all locations when measured by the coordinate clock (observation clock).

According to the Schwarzschild metric, for any two timelike events, referring to special relativity, we can define proper time:

$$d\tau = \sqrt{-ds^2} = \sqrt{\left(1 - \frac{2GM}{r}\right) dt^2 - \left(1 - \frac{2GM}{r}\right)^{-1} dr^2 - r^2(d\theta^2 + \sin^2\theta d\phi^2)}$$

For a light signal at r_1 emitting wavefronts at times t_1 and t'_1, the proper time interval here is the time interval measured by a locally stationary clock. According to the above definition of proper time for two events (13), we clearly have:

$$\Delta\tau_1 = \sqrt{1 - \frac{2GM}{r_1}}\,\Delta t_1 \quad (14)$$

Similarly, for a light signal at r_2 emitting wavefronts at times t_2 and t'_2, we have:

$$\Delta\tau_2 = \sqrt{1 - \frac{2GM}{r_2}}\,\Delta t_2 \quad (16)$$

Both represent the readings of local clocks for one period of the light signal during propagation, i.e., the period values measured by local clocks at the points the light wave passes through. Therefore, the proper frequency defined by the time measured by locally stationary clocks is inversely proportional to the above local clock readings:

$$\nu_1 = \frac{1}{\Delta\tau_1}, \quad \nu_2 = \frac{1}{\Delta\tau_2} \quad (17)$$

Furthermore, based on the above analysis, the time interval measured by the coordinate clock (observation clock) for one phase period of the light signal' s propagation is $\Delta t_1 = \Delta t_2$. If we further assume point 1 is stationary near the Sun and point 2 is stationary on Earth' s surface, we have:

$$\frac{\nu_2}{\nu_1} = \sqrt{\frac{1 - \frac{2GM}{r_1}}{1 - \frac{2GM}{r_2}}} < 1 \quad (18)$$

where ν_2 represents the frequency measured by a stationary clock on Earth, and ν_1 represents the frequency measured by a stationary clock near the Sun. However, it is generally believed that regardless of gravity, the frequency ν_1 of light emitted near the Sun measured by a local stationary clock should equal the frequency ν_2 of the same type of atomic spectrum emitted on Earth measured by an Earth-bound stationary clock, i.e., the characteristic spectrum emitted by the same type of atom locally has a constant frequency when measured by a local clock. Now we find $\nu_2 < \nu_1$, so the observed frequency ν_2' of the propagated light signal is smaller than its local frequency ν_1 when emitted near the Sun, and also smaller than the local frequency ν_2 of the same type of atom emitted on Earth, i.e., a redshift has occurred.

From the above analysis, introducing a strictly uniform coordinate time enables comparison of clock rates at different positions, and the new physical picture of gravitational geometrization can self-consistently explain the solar system's gravitational redshift effect. In mainstream understanding, the redshift is thought to occur because light signals overcome gravitational potential during propagation, rather than being understood as resulting from clocks at the solar surface running slower due to gravity. We believe that for solar system gravitational redshift experiments, both interpretations can temporarily serve as options for now. Whether the essence of gravitational redshift is that the intrinsic rate of clocks truly changes or merely an observational effect of light overcoming gravitational potential ultimately depends on the naturalness and logical reasonableness of the underlying physical picture. This paper tentatively adopts the interpretation that the intrinsic rate of clocks can be physically altered by gravitational interactions.

According to the Schwarzschild metric, for the same physical interval ds, comparing the rates of the coordinate observation clock and the local clock at the same spatial position:

$$\frac{d\tau}{dt} = \sqrt{1 - \frac{2GM}{r}} < 1$$

Since the invariant line element describes the proper physical interval between two events, and events have objective, uniquely determined positions in the spacetime background, the above equation can be understood as: for the same line element in the temporal background, the reading $d\tau$ measured by a local clock in a gravitational field is less than the reading dt measured by the coordinate observation clock (equivalent to a local clock without a gravitational field). Therefore, intuitively, the background rate of the local clock in a gravitational field slows down due to gravity. Similarly, for the same physical interval ds, comparing the lengths of the coordinate observation ruler and the local ruler:

$$\frac{dr_0}{dr} = \sqrt{1 - \frac{2GM}{r}} < 1$$

This can be understood as: for the same line element in the spatial background, the reading dr measured by a local ruler in a gravitational field is greater than the reading dr_0 measured by the coordinate observation ruler (equivalent to a local ruler without a gravitational field). Thus, intuitively, the background length of the local ruler in a gravitational field shortens due to gravity.

6 Implications of the Fine-Tuned Spacetime Physical Picture for Cosmological Problems

The focus of this paper is the proposal that the physical picture of spacetime must conceptually subdivide spacetime into spacetime scale and spacetime background, with relative spacetime scale and absolute spacetime background being dialectically unified. In fact, as pointed out earlier, the spacetime background can be directly perceived. In daily life, any empty region is part of the spatial background. For instance, when an object is removed from a location, the spatial region it originally occupied does not vanish with the object' s removal. The existence of this phenomenon reflects the existence of absolute spatial background. On cosmological scales, the common background for all motion manifested by everything in the universe is the cosmic spatial background. For example, as galaxies continuously recede from each other in the universe, the empty region that emerges between them is a highly approximate cosmic spatial background. It is intuitively difficult to imagine that the cosmic spatial background between galaxies would disappear or shrink as the matter between them disperses. Therefore, if we assume the cosmic spatial background to be the most fundamental background, it should be infinite, and thus the cosmic spatial background itself has no concept of volume size. What is usually referred to as the universe having a size actually means the observable universe. This finite-sized observable universe should be conceptually distinguished from the cosmic spatial background discussed here. According to this principle, what is usually called cosmic expansion should be understood as the expansive motion of the material universe within the cosmic spatial background. Beyond the edge of the material universe, even if there is no matter, we believe that at least the region serving as the spatial background still exists.

Regarding Hubble' s law of cosmic expansion, which shows that the recession velocity of galaxies is proportional to distance, with an absolute background, Hubble' s law can be naturally understood as galaxies corresponding to cosmological comoving coordinate points. The recession between galaxies is not a change in comoving coordinate values but is caused by the background length of local rulers lengthening between fixed comoving coordinate points. Based on the analysis of the physical effects of gravity on local clocks and rulers in the Schwarzschild metric, a local ruler under gravitational influence cuts a shorter length in the spatial background than the coordinate observation ruler without gravity. As the universe expands cosmologically and gravity continuously weakens, the local ruler gradually lengthens. In other words, the spatial compression factor $a(t)$ releases length as the universe expands, thereby conversely explaining the basic physical picture of uniform cosmic expansion.

The existence of an absolute spacetime background necessitates adjustments to the physical picture of gravitational geometrization, and thus the form of the cosmological metric should receive physical correction. A correct cosmological metric should fully satisfy two points: First, gravitational geometrization should be based on a rigid, uniform observer coordinate system. The clock carried by the observer, serving as the standard rate, is extensively replicated throughout spacetime and is called the observation clock. The ruler carried by the observer, serving as the standard length, is extensively replicated throughout spacetime and is called the observation ruler. The effect of gravitational geometrization is described by comparing local clocks and rulers with these mathematically defined observation clocks and rulers. Second, we know that matter density has changed significantly since the birth of the universe. Based on the gravitational time dilation effect confirmed by solar system experiments, the local clock at any comoving point in the universe should tick at different rates along the temporal dimension. Therefore, relative to the long cosmic evolution history studied in cosmology, the time coordinate in the cosmological metric must strictly distinguish between the current Earth observer’ s clock and the comoving local clock. Assuming that clock rates are independent of the observer’ s acceleration and are similarly affected by the gravitational field, a reasonable and self-consistent cosmological metric should be expressed as:

$$ds^2 = -b^2(t)dt^2 + a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta d\phi^2)\right] \quad (19)$$

It can be mathematically verified that the metric shown in equation (19) is actually the most general cosmological metric satisfying the cosmological principle. From this, we obtain the fundamental cosmological equations [?]:

$$3\frac{\dot{a}^2}{a^2} + 3\frac{k}{a^2} = 8\pi G\rho + \Lambda$$

Since velocity and acceleration are not scalars, their values can differ significantly in different observer reference frames. In the cosmic observation coordinate system of the current Earth observer, the mathematical expression describing cosmic acceleration is no longer $\ddot{a} > 0$, but is modified to $\ddot{b} > 0$, because $b(t)$ is the clock coordinate of the current Earth observer. The relationship between the two satisfies [?]:

$$\ddot{b} = -\frac{\dot{a}^2}{a}b + \frac{4\pi G}{3}(\rho + 3p)b$$

Considering that all redshift values of light signals in the universe are measured by the current Earth observer’ s clock, i.e., measured by coordinate time t, the cosmic acceleration value obtained from current observations is directly related to $\ddot{b}$, not $\ddot{a}$. From this, we see that the signs of the two are not necessarily consistent. To illustrate this, we can analogize the evolution properties of the time evolution factor $b(t)$ in the Schwarzschild metric. In the Schwarzschild metric, the time evolution factor $\sqrt{1-\frac{2GM}{r}}$ increases with distance r, equivalent to the time evolution factor increasing with gravitational potential energy. In cosmology, the average gravitational potential energy of the early universe was low, while at present it is high. The current cosmic expansion is a process of reverse increase in gravitational potential energy dominated by expansion; conversely, if the universe begins to contract spontaneously under pure gravity, it would be a process of release and decrease of gravitational potential. Therefore, during cosmic expansion, as gravitational potential energy increases, $b(t)$ will increase with time, i.e., $\dot{b} > 0$. On the other hand, we can easily see that in cosmology, $\dot{a} > 0$. Therefore, even if current observational data [?] yield $\ddot{a} > 0$, according to equation (22) we can still obtain a negative $\ddot{b}$, and thus according to equation (21), we can still have a positive $\ddot{b}$. It is evident that the cosmological metric introduced in this paper, which includes the current Earth observer' s clock, is meaningful for correctly judging cosmic expansion acceleration compared to the FRW metric.

In matters concerning the absolute and the relative, it is necessary to be fully vigilant against moving from one extreme to another. Through logical and dialectical analysis, this paper discusses a spacetime physical picture compatible with the reformulation of classical particle dynamics, the logical deduction of special relativity, and solar system gravitational experiments. Building upon the original concept of spacetime scale, it emphasizes the introduction of the spacetime background concept, pointing out that spacetime scale is essentially the unit spacetime interval (or span) defined by the observer according to proper physical events in concrete objects, while spacetime background is the essential reference foundation for manifesting the magnitude or length of this scale. Therefore, spacetime scale corresponds to the length or span of the line segment cut from the spacetime background by the spacetime basic unit defined according to proper physical event intervals.

The dialectical unity of relative spacetime scale and absolute spacetime background can be naturally presented in various relevant physical theories, as proven in this paper. First, only on the basis of this fundamental physical picture of spacetime can a new particle dynamics equation with obvious formal superiority be naturally derived within the classical mechanics framework, thereby strongly supporting the existence of an absolute spacetime background. Second, special relativity' s assumption that events have objective, uniquely determined positions in spacetime, with Lorentz coordinate transformations directly understandable as transformations between spacetime scales, means that special relativity actually presupposes the existence of an absolute spacetime background. Finally, in the theory of gravitational geometrization, this paper proposes abandoning Einstein' s equivalence principle and principle of general relativity, primarily based on both mathematical and physical reasons. Physically, the nature of inertial forces has been revealed as the real force on the reference object after mass equalization, which can be gravity, friction, tension, or various other interactions. More importantly, inertial forces are not applied to the examined object but to the reference object. Therefore, Einstein' s equivalence principle does not hold, and the principle of general relativity, with the equivalence principle as its "midwife," is also untenable. On the other hand, mathematically, it is well known that for a physically rotating rigid body reference frame, determining all its kinematic properties requires at least four points on different faces. Therefore, referring to the successful experience of reformulating the particle dynamics equation, when constructing dynamical equations with a physically rotating reference frame, the equations must theoretically incorporate the force and motion descriptions of at least four reference particles while maintaining a simple form. This is obviously difficult and has at least not been naturally achieved so far. Given the abandonment of Einstein' s equivalence principle and principle of general relativity, the observation theory in gravitational geometrization should be reconstructed, no longer introducing the concepts of standard clocks defined by line element and observer tetrad theory as in general relativity. Instead, according to the new understanding of gravitational geometrization, local clocks' ticking rates in the temporal background slow down under gravitational influence, while local rulers' lengths cut in the spatial background shorten under gravitational influence.

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Note: Figure translations are in progress. See original paper for figures.