Newtonian Gravity as a Gradient of Time:
the Weak-Field Limit of General Relativity, the Metric Price of Space, and the Shapiro Delay

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Abstract

It is shown that in the weak-field static limit of general relativity, the gravitational acceleration of slowly moving bodies is determined by the gradient of the time component of the metric, g_{00}, or equivalently by the gradient of the local lapse N. **This is not an alternative theory and not a metaphorical reinterpretation, but a direct consequence of the geodesic equation: in the non-relativistic regime, terms containing spatial velocities are suppressed by powers of v/c, and at leading order only the contribution of $\Gamma^i{}_{00}$, set by g_{00}, survives.** Historically, this boundary is already visible in Einstein's 1911 calculation: the temporal, "Newtonian" part gives half of the light deflection at the Sun, while the full 1915 general relativity, which includes the spatial metric, gives the doubled value confirmed by the 1919 observations. The physical meaning of the result is discussed further. The popular rubber-sheet analogy is useful for visualizing curvature, but it does not explain the cause of falling: a ball rolls into a dimple only in the presence of an already-given external force. In the Newtonian sector of general relativity, this missing force has an exact source: the gradient of the rate of time. The Newtonian sector can therefore be understood as the source of the effective force of gravity for slow matter, while the full Einsteinian sector sets the complete shape of the gravitational "pit": its temporal depth, its spatial extent, and its optical action on light. A cautious "hole"-type analogy is also introduced: in the passive Newtonian sector there is no need to posit a new particle carrying a "temporal charge"; the carrier of the response can instead be interpreted as the bound energy of matter itself — that is, mass, described in the language of an effective temporal cavity.

Keywords: *weak-field limit of GR; geodesic equation; gravitational redshift; lapse; light deflection; PPN parameter γ; Newtonian sector; hole conduction; gravitational time dilation.*

1. Introduction

Popular accounts of general relativity almost always begin with geometry: the four-dimensional manifold, tensors, curved spacetime as a single whole. It is easy to conclude from this that the picture of gravity as a gradient of the pace of time is merely a loose philosophical image. This is not so.

It follows directly from the geodesic equation of GR that in a static weak field and at small velocities $v \ll c$, the leading contribution to the acceleration of free fall is determined by the time component of the metric, or the lapse N. The terms of the geodesic equation that contain spatial velocities carry additional factors of order v/c and vanish at leading non-relativistic order. So this is not a new postulate, but the standard Newtonian limit of GR.

In weak static fields — for instance, at the surface of the Earth — the statement "the gravitational acceleration of a slowly moving body is determined by the gradient of the rate of time" is a rigorous mathematical fact of GR itself. This is precisely its Newtonian limit. The following sections show this step by step: first through a critique of the popular rubber-sheet analogy, then historically, through Einstein's early calculation, and finally mathematically, through the geodesic equation.

At the same time, it is important to bound the claim immediately. The formula "gravity is a gradient of time" is exact for slowly moving matter in a weak static field. It does not replace full GR. Light, the Shapiro delay, rotating sources, and gravitational waves require the spatial, mixed, and dynamical parts of the metric. This is exactly why the article distinguishes two levels: the Newtonian sector as the source of the effective force of gravity for slow matter, and the full Einsteinian sector as the complete shape of gravitational geometry.

2. Why the "ball in a pit" image is insufficient

One of the best-known popular pictures of gravity is a ball on a rubber sheet. A large ball creates a depression, and a small ball rolls toward it. As a visualization of curvature this picture is useful. But as a causal explanation of gravity it hides a problem.

A ball rolls into the pit not because the pit itself carries a force. It rolls because an external force of gravity already exists, pressing the ball onto the rubber sheet and making it move down the slope. Without this external force, the rubber pit would not make the ball fall. So this analogy in effect explains gravity through gravity already assumed.

In the Newtonian sector of GR the situation is different. Here no external force is needed to additionally "push" a body into the geometric well. For slowly moving matter, the role of this force is played by the gradient of the rate of time. Mass-energy changes the metric; the metric sets an uneven rate for local clocks; the gradient of this clock rate creates acceleration.

$$mass\text{–}energy \rightarrow g_{\mu\nu} \rightarrow N(x) \rightarrow \nabla N \rightarrow a$$

Here $N(x)$ is the local lapse — that is, the rate of static clocks relative to the chosen time. In a weak static field, the leading Newtonian force for slow matter is determined precisely by the gradient of this lapse:

$$a = -c^2 \ \nabla \ln N \quad (1)$$

So a more precise popular formulation would read: gravity in the Newtonian sector is not a ball falling into a spatial pit, but the motion of slow matter in a gradient of the local rate of time.

3. Historical path: 1907–1919

Historically, this conclusion is not a retrospective fantasy. Einstein's early path to gravity indeed began with a change in the rate of time and in the propagation of light in a gravitational field, well before the full Riemannian geometry of 1915.

In the period 1907–1912, Einstein did not yet have the final geometric form of GR. In his 1911 paper "On the Influence of Gravitation on the Propagation of Light" he introduces a dependence of the speed of light on the gravitational potential and, using Huygens's principle, computes for the first time the expected deflection of a starlight ray passing near the edge of the Sun.

Einstein’s 1911 numerical result, about 0.83 arcseconds, coincides with the purely Newtonian calculation of light deflection treating light as a particle. This is not a coincidence: a theory in which, in effect, only the temporal part of gravity is at work will, by construction, give the Newtonian contribution.

By 1915, having built the full geometric version of the theory, in which not only clocks but also the spatial part of the metric are curved, Einstein obtained a value twice as large — about 1.75 arcseconds. The difference arises because, for light, the temporal and spatial contributions turn out to be equal in magnitude.

Arthur Eddington’s expedition to the island of Príncipe and to Sobral in 1919, observing a solar eclipse, gave results consistent precisely with the doubled, full Einsteinian value. The historical lesson is therefore this: the temporal part accounts for the Newtonian contribution, but the full relativistic optics also requires spatial curvature.

4. Mathematical proof: the geodesic equation

The equation of motion of a freely falling body in GR is the geodesic equation:

$$d^2x^\mu/d\tau^2 + \Gamma^\mu{}_{\alpha\beta}(dx^\alpha/d\tau)(dx^\beta/d\tau) = 0 \quad (2)$$

The transition to a derivative with respect to coordinate time t is carried out at leading non-relativistic order, $v \ll c$. In this approximation, the terms with spatial velocities are suppressed, and the spatial part of the geodesic equation reduces to

$$d^2x^i/dt^2 \approx -c^2\, \Gamma^i{}_{00} \quad (3)$$

Key remark: this suppression is not an additional approximation or a new physical postulate. It is the ordinary non-relativistic limit of the geodesic equation: the terms containing spatial velocities carry extra factors of order v/c or $(v/c)^2$, while the leading term contains $\Gamma^i{}_{00}$ and is set by the time component of the metric.

In a static weak field, the corresponding Christoffel symbol is expressed through the derivative of the time component of the metric:

$$\Gamma^i{}_{00} = -(1/2)\, \eta^{ij}\, \partial_j\, g_{00} \quad (4)$$

Substitution gives the acceleration through the gradient of the time component of the metric alone:

$$a = (1/2)c^2\, \nabla g_{00} \quad (5)$$

For the standard weak-field form

$$g_{00} = -(1 + 2\Phi/c^2)$$

this gives exactly Newton’s law:

$$a = -\nabla\Phi \quad (6)$$

The same thing can be written through the lapse N. In a weak field, $N \approx 1 + \Phi/c^2$, so

$$a = -c^2\, \nabla \ln N \quad (7)$$

This derivation matters because it is not a new force hypothesis. It follows from the geodesic dynamics of GR itself in a static weak field. For slow bodies the spatial velocity components are small, so the leading contribution to the acceleration is given precisely by g_{00}, or equivalently by the lapse N. The spatial part of the metric does not disappear from the theory, but it does not participate in the leading Newtonian acceleration of slow matter.

5. What makes a body fall into the "pit"?

We can now answer precisely the question that the rubber-sheet analogy leaves unanswered. What force makes a body fall into the pit? In the Newtonian sector of GR the answer is clear: it is the gradient of the local rate of time.

In popular language one can put it this way: the Newtonian sector supplies the "force" that makes a body fall into the pit. The full Einsteinian sector sets the geometry of the pit itself: its temporal depth, its spatial extent, and its optical action on light.

Even more briefly:

The Newtonian sector is the cause of the falling of slow matter.

The Einsteinian sector is the complete shape of the gravitational pit.

In precise language this means the following. The Newtonian sector corresponds to the temporal part of the metric:

$$g_{00} \quad \text{or} \quad N(x)$$

It is responsible for the acceleration of slow matter:

$$N(x) \rightarrow \nabla \ln N \rightarrow a$$

The full Einsteinian sector includes not only the temporal but also the spatial, mixed, and dynamical parts of the metric:

$$g_{00} + g_{ij} + g_{0i} + \text{dynamics of } g_{\mu\nu}$$

It is not needed for a slow apple to start falling: the leading cause of that falling is already contained in g_{00}. It is needed for the full geometry: for light deflection, the Shapiro delay, frame dragging, and gravitational waves. This is why the word "reinforcement" is correct chiefly for the optical case: the temporal part gives half of the light deflection, and the spatial part adds an equal second contribution.

It is important not to mix the two languages. In the full language of GR a freely falling body is not "pushed" by a force: it moves inertially along a geodesic. But in the Newtonian language, tied to an observer at rest, this same geodesic motion is described as acceleration under the action of the force of gravity. This article shows that this effective Newtonian force has a temporal nature: it arises from the gradient of the local rate of clocks. So a rubber pit without a temporal slope remains only a picture of geometry; it is precisely the g_{00} sector that turns it into a dynamical gravitational funnel for slow matter.

Curvature by itself is not a Newtonian force acting on an individual particle. Curvature sets the geometric structure and manifests itself, in particular, through tidal effects and the relative deviation of neighboring geodesics. Force-language appears only when free geodesic motion is described from the frame of an observer at rest.

Put more simply: the spatial pit shows where the geometry is curved; the temporal slope explains why a slow body falls there. The temporal slope provides the Newtonian fall of slow matter, while the spatial curvature sets the full geometric and optical structure of the gravitational pit.

More precisely, for light the spatial part of the metric should not be described as an additional Newtonian force. It does not make light move locally faster or slower than c. Its role is optical: it changes the spatial, or optical, path length. In this sense, the gravitational deflection of light can be described as refraction in an effective optical geometry, rather than as a force pulling photons toward the surface.

This analogy must be used with care. Unlike ordinary material refraction, the leading vacuum result of GR is non-dispersive: different wavelengths, in the geometric-optics limit, follow the same null geodesics. Frequency-dependent interference, diffraction, or rainbow-like structure can arise only in wave-optical regimes of gravitational lensing or in an actual dispersive medium, but not as the leading vacuum deflection effect.

6. What is the carrier of the response to the time gradient?

If the gravitational acceleration of slowly moving matter is determined by the gradient of the local rate of time, a natural question arises: what exactly responds to this gradient?

In electromagnetism, the electric field acts on electric charge:

$$F = qE \quad (8)$$

In gravity there is no need to introduce a new “temporal-charge” carrier particle. The role of such a carrier is already played by matter itself, as bound energy. Here the analogy with hole conduction in semiconductors is useful.

A hole in a semiconductor is not a fundamental particle. It is the absence of an electron in a filled electron sea. Nevertheless, a hole behaves as an effective positive charge carrier and participates in electric current. Likewise, the gravitational response to a time gradient can be understood not as an action on a new particle, but as an action on a local region of bound energy — on an effective temporal cavity of matter.

An atom, in this language, is a portable region of bound energy. Its mass is not a “solid substance” in the naive sense, but a measure of the energy enclosed in a stable structure. So the carrier of the Newtonian gravitational response is not a separate chronon and not a new particle, but the body’s own mass-energy.

More precisely, “temporal cavity” here does not mean a void or a new substance, but a cautious language for describing mass-energy as the carrier of the response to the gradient of the rate of time. The energy of an atom — nuclear, electronic, field, and binding energy — forms its mass-energy. In this interpretation, bound energy is regarded as the carrier of a local temporal response — that is, a response tied to the time component of the weak-field metric. So the temporal cavity does not arise as an addition to the atom, but as the interpretive meaning of mass itself: mass is a measure of bound energy, and bound energy is the carrier of the local gravitational response.

$$Q_T \sim E/c^2$$

In the passive Newtonian sector this is simply the ordinary gravitational mass:

$$Q_T = M$$

Status of the analogy.

This analogy does not prove the existence of a new microscopic medium of time, does not derive the weak equivalence principle from first principles, and does not introduce a new, experimentally independent charge. In the passive Newtonian sector, the statement $Q_t = M$, where it is used, is not a new prediction but a constitutive restatement of the already-known equality between inertial and gravitational response. In other words, this is not a derivation of the weak equivalence principle but an interpretation of it: the same bound energy that sets a body's inertial mass also serves as the carrier of its passive gravitational response.

Weight is then written with no new physics:

$$W = Mg$$

Weight is not a constant of the body, but the response force of its temporal cavity to an external gradient in the rate of time. What remains a constant characteristic of the body in this approximation is its mass-energy; weight arises only once this mass-energy is placed in a specific gravitational field — that is, in a specific gradient of the rate of time.

What is new here is not the force law, but the interpretation of its carrier: matter behaves as a local temporal cavity — a region of bound energy with which a local slowing of time is associated — and weight is the action of the external gradient in the rate of time on this cavity. This analogy does not change Newton's law and does not introduce a new particle; it only clarifies that in the Newtonian sector, the role of the carrier of the response is played by the body's own mass-energy.

7. The precise boundary of applicability

The preceding sections do not mean that the whole of gravity reduces only to g_{00}. They mean something more precise: at leading order, for slowly moving matter, the time component of the metric suffices. For light and other relativistic phenomena, the spatial part of the metric is also required.

Spatial curvature is not negligible in magnitude. In a weak field, the perturbations of g_{00} and g_{ij} are of the same order, roughly Φ/c^2. It is wrong to say that "almost all of geometry is time." The correct statement is different: spatial curvature does not enter the equation of motion of a slow body at leading Newtonian order, but it does enter the optics and the full relativistic picture.

Thus, for slow matter, g_{00} gives the effective Newtonian acceleration. For light and other waves, not only the temporal but also the spatial part of the metric is required: $g_{00} + g_{ij}$ set the optical geometry that determines light deflection and the Shapiro delay.

In a weak field it is convenient to write the spatial part of the metric in PPN form,

$$g_{ij} = (1 + 2\gamma q_N)\delta_{ij}, \quad q_N = GM/(rc^2) = -\Phi/c^2 > 0$$

So near a mass, where $q_n > 0$, the metric price of one and the same coordinate spatial interval increases. For a fixed coordinate interval dx, the proper, or optical, path length turns out to be larger than in the flat background, where $g_{ij} \to \delta_{ij}$.

This is exactly what should be understood by the cautious phrase "space near a mass is stretched." It is not about a visual stretching of a rubber surface, and not about a new force acting on light, but about the fact that one and the same coordinate path has a greater metric length near a mass than far from it.

The Shapiro delay should be understood in the same language. Light is not slowed as a particle under the action of a force: locally it still moves at speed c. The delay arises because, for a distant observer, the optical travel time increases: the temporal part of the metric slows the rate of clocks, and the spatial part increases the metric path length.

In the standard Schwarzschild form this is seen directly:

$$g_{rr} = 1/(1 - r_s/r) \ > \ 1, \qquad d\ell_r = dr/\sqrt{(1 - r_s/r)} \ > \ dr$$

That is, near a mass the radial proper distance is larger than the corresponding flat coordinate distance. Far from the mass this spatial addition does not turn into a new "expansion," but tends to zero:

$$g_{rr} \to 1, \quad N \to 1$$

In other words, far away the metric returns to the flat background. So the Shapiro delay is not a force-based braking of light, but an increase in the optical travel time in a region where the rate of clocks is simultaneously slowed and the spatial metric price of the path is increased.

Observable / regime	What is involved
Slow body (an apple, a GPS satellite in the Newtonian approximation, planetary orbits)	The leading contribution is given by g_{00} or the lapse N. Acceleration: $a = -c^2\nabla \ln N$.
Light / ultrarelativistic matter (light deflection, the Shapiro delay)	g_{00} and g_{ij} are both required. In GR the spatial contribution adds the second half of the effect.
Rotating source (e.g., the Earth)	Mixed components g_{0i} additionally appear: gravitomagnetic and frame-dragging effects.
Gravitational waves	Metric dynamics and tensor degrees of freedom are needed; a single static temporal gradient is not enough.

A present-day test of the ratio of temporal to spatial contributions has been carried out, in particular, in Cassini-type experiments on the Shapiro delay. The results constrain the PPN parameter γ to be close to $\gamma = 1$, corresponding to the full Einsteinian spatial response, not only the temporal part.

8. What remains outside this picture

First, the split of the metric into "temporal" and "spatial" parts depends on the choice of coordinates. In this article it is used in the standard weak-field static sense, where this split has a clear operational interpretation through static clocks and the Newtonian limit.

Second, for rotating sources, mixed components g_{0i} appear. These reduce neither to a simple slowing of time nor to static spatial curvature. Such effects have been measured, for instance, in frame-dragging experiments.

Third, dynamical gravitational waves require tensor degrees of freedom. They cannot be derived from a single scalar field for the rate of time alone.

This is exactly where the boundary lies between the strong popular interpretation of a Newtonian force and the full theory of gravity. Explaining the fall of slow matter through a gradient of time is already possible within weak-field GR. Explaining light, the Shapiro delay, frame dragging, and gravitational waves through a single temporal gradient alone is not possible: the full Einsteinian sector is needed for that.

9. Experimental confirmation of gravitational time dilation

Independently of the question of light deflection, the very fact of gravitational time dilation has been confirmed experimentally many times over.

In 2010 a NIST group compared two aluminum-ion optical clocks separated in height by 33 cm, and directly registered the difference in clock rate. The popular phrasing “the head ages faster than the feet” refers precisely to this effect.

In 2022 a JILA group measured the gravitational redshift on a scale of about a millimeter, using a cloud of ultracold strontium atoms. This showed that the dependence of the rate of time on gravitational position has direct laboratory meaning even at very small heights.

These experiments do not prove a new theory of gravity. They confirm a more basic fact, sufficient for the purposes of this article: the rate of time does indeed depend on gravitational position, and therefore expressing the Newtonian force through the gradient of clock rate has physical, not merely formal, meaning.

10. Conclusion

For slowly moving matter, the acceleration of free fall is determined by the gradient of the time component of the metric. This is not an alternative theory and not an arbitrary philosophical interpretation, but a rigorous result of the Newtonian limit of general relativity: it follows directly from the geodesic equation that, in a static weak field and at small velocities, the leading contribution to the acceleration is set by g_{00}, or the lapse N.

The popular picture of a ball in a spatial pit is useful as an image of curvature, but it does not explain the cause of falling: the ball rolls only in the presence of an external force. In the weak-field sector of GR the causal structure is clearer. The Newtonian sector supplies the “force” that makes a body fall into the pit. The full Einsteinian sector sets the geometry of the pit itself: its temporal depth, its spatial extent, and its optical action on light.

This can be put briefly as follows: the Newtonian sector is the cause of the falling of slow matter; the Einsteinian sector is the complete shape of the gravitational pit.

There is no need to posit a new particle as the carrier of the response to the time gradient. In the passive Newtonian sector, this role is played by the bound energy of matter itself — that is, by mass. In this language, a “temporal cavity” means not a new substance, but an interpretive picture of mass-energy as the carrier of the response to an external gradient in the local rate of time. In this language, weight is not an intrinsic constant of the body: the intrinsic characteristic remains the mass-energy, while weight is the force that holds this mass-energy in place within a given gravitational field. The term “temporal cavity” does not change the standard law W = Mg and does not imply weight control within the scope of this article. It is used only as an interpretive language for the fact that, in the Newtonian sector, the carrier of the gravitational response is the body's own mass-energy.

The domain of applicability of this picture is limited. For light, the Shapiro delay, rotating sources, and gravitational waves, the spatial, mixed, and dynamical parts of the metric are required. So the formula "gravity is a gradient of time" is exact for the Newtonian sector of slow matter, but it does not replace the full general theory of relativity.

The distinction can be stated compactly: g_{00} governs the Newtonian fall of slow matter, while $g_{00} + g_{ij}$ govern the gravitational refraction of light and the Shapiro delay. The first looks, in Newtonian language, like an effective force; the second is an optical-geometric effect, not a force acting on light in the ordinary mechanical sense.

The Shapiro delay shows the same boundary: light takes longer not because a force brakes it, but because near a mass the optical path length and optical travel time increase. The metric price of one and the same coordinate interval is larger there than in the flat background; far from the source this spatial deformation vanishes, and the metric returns to its flat form.

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