Gravity Inside the Dirac Adjoint: Mass Renormalization and Geometry from the Rotor Field Qg

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Abstract

This paper develops a new way to connect quantum theory and gravitation by placing geometry inside the structure of the Dirac equation itself. A single mathematical object, the gravitational rotor field Qg, replaces the fixed time direction of flat spacetime with a locally curved one. When this rotor is introduced into the Dirac adjoint, the theory automatically reproduces three familiar regimes: ordinary flat space, the weak-field limit that gives gravitational redshift, and the strong-field domain where curvature and its gradients affect the motion of matter. In this formulation, gravity acts by changing the local measure of time and therefore the effective mass of particles. Massive Dirac particles experience this as a renormalization of their rest mass, while massless Weyl particles can acquire a small, curvature-induced mass. The framework thus unifies flat, weak, and strong gravitational behavior inside a single operator, without introducing an external metric or new postulates. It preserves the tested limits of general relativity yet extends them into a directly quantum setting, offering a new language in which mass, curvature, and the flow of time emerge as different aspects of one spinorial geometry.

Contents

1 Introduction

The search for a coherent bridge between quantum theory and gravitation remains one of the central aims of modern theoretical physics. Despite the empirical success of both the Standard Model (SM) and general relativity (GR), their mathematical frameworks remain distinct: quantum fields are defined on a fixed spacetime background, while geometry in GR is treated as an external, classical structure. This separation leaves fundamental quantities such as mass, gravitational redshift, and the flow of time as external inputs to the quantum formalism.

In earlier work [1, 2], the algebraic foundation for a spinorial unification was established using a biquaternion formulation of the Lorentz group and of the Dirac and Weyl matrices. The 2020 study [1] constructed the complete set of biquaternion operators generating Lorentz transformations, providing the algebraic infrastructure in which both spinor dynamics and spacetime symmetry arise from a common quaternionic basis. The 2025 paper [2] extended this construction by embedding the Dirac adjoint into a geometric framework that identifies the lapse and shift of general relativity with the components of a local biquaternionic time-flow field. That work introduced the idea that gravitation may be described as a *rotor field* acting directly on the quantum inner product of the Dirac equation.

The present paper completes this development by formulating the *gravitational rotor field* $Q_g(x)$ as a position–dependent Lorentz transformation that acts within the Dirac adjoint itself,

$$\bar{\Psi}_g = \Psi^\dagger \, Q_g^{-1}\gamma_0 Q_g.$$

Through this single substitution, geometry becomes an intrinsic part of the spinor algebra rather than an external metric background. The rotor replaces the fixed time axis of Minkowski space with the local time direction $e_0(x) = Q_g^{-1}\gamma_0 Q_g$, producing the correct flat, weak, and strong–field limits in one covariant operation.

The resulting formalism yields an effective mass term

$$m_{\text{eff}}(x)c = m_0 c \, \cosh\psi_g(x) + \frac{\hbar}{c}(\partial_\mu \psi_g)\, u^\mu,$$

showing that curvature both renormalizes existing rest masses and can generate effective mass for massless Weyl fields through gradients of the gravitational rapidity $\psi_g(x)$. In the weak–field limit, the familiar gravitational redshift $m_g = m_0 e^{\phi/c^2}$ is recovered as an *internal mass renormalization* of the Dirac Hamiltonian itself.

This approach differs from conventional unification attempts—such as Einstein–Cartan, scalar–tensor, loop, or string frameworks—in that it places geometry *inside* the quantum adjoint, making the equivalence principle an identity of the algebra rather than an external postulate. Flat spacetime, weak–field redshift, and strong–field curvature are all covered by the same operator $Q_g^{-1}\gamma_0 Q_g$, providing a single algebraic mechanism for gravitational effects.

The paper is organized as follows. Section 2 defines the gravitational rapidity field $\psi_g(x)$ and the corresponding rotor $Q_g(x)$. Section 3 derives the covariant Dirac equation with the modified adjoint and interprets the resulting mass renormalization as an intrinsic form of gravitational redshift. Section 4 extends the formalism to massless spinors, where curvature induces an effective mass. Section 5 discusses the phenomenological implications and comparison with other unification schemes. Section 6 concludes with the broader perspective that mass, curvature, and time flow represent different manifestations of a single spinorial geometry.

1 Mass Generation and Modulation by the Rotor Field $Q_g(x)$

1.1 In QFT / standard Dirac theory

In relativistic quantum field theory a fermion is an excitation of a spinor field $\Psi(x)$ that satisfies the Dirac equation

$$(i\hbar\gamma^\mu \partial_\mu - m_0 c)\Psi = 0. \tag{1}$$

The mass term $m_0 c\,\Psi$ couples left– and right–handed components of the spinor and thereby breaks chiral symmetry. Geometrically, the γ_0 appearing in the adjoint $\bar{\Psi} = \Psi^\dagger \gamma_0$ defines a fixed global time direction in Minkowski space, required for the construction of Lorentz scalars such as $\bar{\Psi}\Psi$ and $\bar{\Psi}\gamma^\mu\Psi$.

Hence, in standard Dirac theory, mass is an external constant parameter that couples the spinor field to a fixed timelike direction of spacetime.

2.1 Operational definition of the gravitational rapidity field $\psi_g(x)$ and construction of the rotor $Q_g(x)$

The *gravitational rapidity field* $\psi_g(x)$ quantifies the local tilt of the time axis with respect to an inertial observer. Operationally, it is defined through the ratio of local proper time $d\tau$ to coordinate time dt, measured for a standard clock momentarily at rest in the gravitational field:

$$\cosh \psi_g(x) = \frac{dt}{d\tau} = \frac{1}{\sqrt{-g_{00}(x)}}, \qquad \sinh \psi_g(x) = \frac{v_g(x)}{c} = \sqrt{\frac{g_{00}^{-1} - 1}{1}}, \tag{2}$$

so that $\psi_g(x)$ represents the local *hyperbolic angle of time dilation* between the global inertial frame and the local flow of proper time. In the weak–field limit one obtains

$$\psi_g(x) \simeq \frac{\phi_N(x)}{c^2},$$

where ϕ_N is the Newtonian potential. Gradients of ψ_g measure the spatial and temporal variation of gravitational time flow: $(\partial_\mu \psi_g)u^\mu$ represents the rate of change of the local rapidity along a particle worldline.

Construction of the gravitational rotor. The gravitational rotor field $Q_g(x)$ is the local Lorentz transformation that maps the global time axis γ_0 to the local direction of time flow $e_0(x)$ defined by the rapidity field $\psi_g(x)$. It acts as a position–dependent boost in the direction $\hat{\mathbf{n}}(x)$ of the local gravitational inflow and is given by

$$Q_g(x) = \exp\left[-\frac{1}{2}\,\psi_g(x)\,\hat{\mathbf{n}}(x)\cdot\boldsymbol{\beta}\right], \qquad \boldsymbol{\beta} = (\gamma_1\gamma_0,\, \gamma_2\gamma_0,\, \gamma_3\gamma_0). \tag{3}$$

Under this rotor,

$$e_0(x) = Q_g^{-1}(x)\,\gamma_0\,Q_g(x), \qquad e_i(x) = Q_g^{-1}(x)\,\gamma_i\,Q_g(x), \tag{4}$$

so that the tetrad $\{e_\mu(x)\}$ is generated algebraically from the rapidity field itself. The connection and curvature follow from

$$\not{G}_\mu(x) = Q_g^{-1}(x)\,\partial_\mu Q_g(x), \qquad F_{\mu\nu}(x) = [D_\mu, D_\nu], \tag{5}$$

establishing a one–to–one correspondence between the rapidity field $\psi_g(x)$, the local rotor $Q_g(x)$, and the spacetime geometry experienced by the Dirac field.

1.2 Definition of the Gravitational Rotor Field

The gravitational rotor field $Q_g(x)$ is defined as the local Lorentz boost that carries the global inertial time axis γ_0 into the local time axis $e_0(x)$ of the curved spacetime. It is parametrized by the *gravitational rapidity field* $\phi_g(x)$ and a local boost direction $\hat{\mathbf{n}}(x)$ as

$$Q_g(x) = \exp\left[-\frac{1}{2}\,\phi_g(x)\,\hat{\mathbf{n}}(x)\cdot\boldsymbol{\beta}\right], \qquad \boldsymbol{\beta} = (\gamma_1\gamma_0, \gamma_2\gamma_0, \gamma_3\gamma_0). \tag{6}$$

The associated local basis vectors are obtained by conjugation,

$$e_0(x) = Q_g^{-1}(x)\gamma_0 Q_g(x), \qquad e_i(x) = Q_g^{-1}(x)\gamma_i Q_g(x), \tag{7}$$

so that the rotor field generates the local tetrad $\{e_\mu(x)\}$ and defines the spin connection $\not{G}_\mu = Q_g^{-1}\partial_\mu Q_g$. The scalar field $\phi_g(x)$ represents the local *gravitational rapidity*—the hyperbolic angle between the global and local time directions. In the weak-field limit it reduces to $\phi_g \simeq \phi_N/c^2$, where ϕ_N is the Newtonian potential.

1.3 Dirac theory in the gravitational rotor field $Q_g(x)$

In the present framework this fixed direction becomes dynamical through the *rotor field*

$$\gamma_0(x) = Q_g^{-1}(x)\,\gamma_0\,Q_g(x), \qquad \bar{\Psi}_g = \Psi^\dagger Q_g^{-1}\gamma_0 Q_g. \tag{8}$$

The field $Q_g(x) \in \mathrm{Spin}(1,3)_{\mathbb{C}}$ generates the local Lorentz frame; its derivative defines the spin connection

$$\not{G} = Q_g^{-1}\not{\partial} Q_g, \qquad D_\mu\Psi = \partial_\mu\Psi + \tfrac{1}{2}\not{G}_\mu\Psi, \tag{9}$$

and the curvature $F_{\mu\nu} = [D_\mu, D_\nu]$. Wherever the boost component of Q_g—equivalently the gravitational rapidity field $\psi_g(x)$—is nonzero, the local time axis is tilted relative to the global one. This tilt mixes left and right spinor components, producing an *effective mass coupling.*

Substituting the rotor-dressed adjoint into the Dirac Lagrangian

$$\mathcal{L}_D = \frac{i\hbar c}{2}\Big(\bar{\Psi}_g\gamma^\mu D_\mu\Psi - D_\mu\bar{\Psi}_g\,\gamma^\mu\Psi\Big) - m_0c^2\,\bar{\Psi}_g\Psi, \tag{10}$$

one obtains cross terms from the derivative of the rapidity field contained in $\not{G}_\mu$. To lowest order these terms generate the local effective mass

$$\boxed{m_{\text{eff}}(x)c = m_0c\cosh\psi_g(x) + \frac{\hbar}{c}\,(\partial_\mu\psi_g)\,u^\mu.} \tag{11}$$

Equivalently, one may express the gravitational renormalization of mass as

$$\boxed{m_0 \;\longrightarrow\; m_g(x) = m_0\,\Gamma_{\text{grav}}(x), \qquad \Gamma_{\text{grav}}(x) = \cosh\psi_g(x) + \frac{\hbar}{m_0c^2}\,(\partial_\mu\psi_g)\,u^\mu.} \tag{12}$$

This relation makes explicit that the rotor field $Q_g(x)$ transforms the constant rest mass m_0 into its local, gravitationally shifted value $m_g(x)$ through the dimensionless factor $\Gamma_{\text{grav}}(x)$.

1.4 Interpretation of the effective mass

Equation (11) separates two distinct regimes:

(a) Rest–mass present ($m_0 \neq 0$). The particle already possesses an invariant rest mass m_0. The first term in (11) represents a *gravitational modulation* of that mass through the local rapidity field,

$$m_g(x) = m_0\cosh\psi_g(x), \tag{13}$$

while the derivative term adds a small kinematic correction due to gradients of ψ_g. Thus the rotor field transforms the constant rest mass into its *gravitationally redshifted* value $m_g(x)$; it does not create mass from nothing.

(b) Massless spinor ($m_0 = 0$). For a purely Weyl (massless) spinor, the first term vanishes but the second remains:

$$m_{\text{geom}}(x)c = \frac{\hbar}{c}\,(\partial_\mu\psi_g)\,u^\mu. \tag{14}$$

In a region where the rapidity field varies, the spinor acquires an *effective geometric mass* even though its rest mass is zero. This demonstrates that a nontrivial gravitational rotor field can *induce mass purely from geometry.*

1.5 Physical meaning

- The boost part of $Q_g(x)$ (encoded by ψ_g) corresponds to local gravitational time dilation. When inserted in the Dirac adjoint, it mixes left and right spinor components and shifts their rest mass.
- The derivative coupling $(\partial_\mu\psi_g)u^\mu$ converts spatial or temporal variation of the rapidity field into inertial energy, providing a purely geometric mechanism for mass generation.
- The standard Dirac mass m_0 thus becomes the *flat–space limit* of a more general relation where geometry and inertia are inseparable.

2 Approximation to the Newtonian limit

In a static, weak gravitational field the local rapidity field $\psi_g(x)$ varies slowly in space and time, so that the derivative coupling term in (12) can be neglected:

$$u^\mu\partial_\mu\psi_g \approx 0 \qquad \Longrightarrow \qquad \Gamma_{\text{grav}}(x) \simeq \cosh\psi_g(x). \tag{15}$$

The effective mass then reduces to

$$m_g(x) \simeq m_0\,\cosh\psi_g(x). \tag{16}$$

Weak–field (small–rapidity) expansion. For $|\psi_g| \ll 1$,

$$\cosh\psi_g \simeq 1 + \tfrac{1}{2}\psi_g^2. \tag{17}$$

In the hidden–velocity formulation the Newtonian potential $\phi(x)$ is related to the rapidity by

$$\phi(x) \;\simeq\; \tfrac{1}{2}\,c^2\,\psi_g^2(x) \qquad (\text{since } v_\phi^2/2 = \phi). \tag{18}$$

Substituting (18) into (16) gives

$$m_g(x) \simeq m_0\Big(1 + \frac{\phi(x)}{c^2}\Big) \simeq m_0\,e^{\phi(x)/c^2}, \tag{19}$$

valid to first order in ϕ/c^2.

Exact exponential form. If desired, one can define the potential through the identity

$$\phi(x) \;\equiv\; c^2\ln\!\big[\cosh\psi_g(x)\big], \tag{20}$$

so that Eq. (16) becomes exact:

$$\boxed{m_g(x) = m_0\,e^{\phi(x)/c^2}}. \tag{21}$$

This expression coincides with the standard gravitational redshift factor for energy or frequency in a stationary metric, confirming that the rotor–field formulation reproduces the Newtonian limit of general relativity when the rapidity field ψ_g is small and time–independent.

Validity of the approximation. Equation (19) holds under the following conditions:

- the field is *static* or the observer is at rest relative to the local gravitational flow ($u^\mu \partial_\mu \psi_g \simeq 0$);
- rapidities are small, $|\psi_g| \ll 1$, or equivalently $|\phi|/c^2 \ll 1$;
- higher–order derivatives of ψ_g may be neglected.

Under these assumptions the gravitational modulation of the rest mass reduces to the familiar exponential redshift:

$$m_g(x) = m_0 e^{\phi(x)/c^2}.$$

Thus the rotor field reproduces the standard weak–field limit of gravitational redshift and energy scaling, showing that the same geometric mechanism which generates mass in curved time flow also yields the exponential redshift relation of Newtonian gravity.

3 Phenomenology of Mass Renormalization

The interaction of the gravitational rotor field $Q_g(x)$ with fermionic matter modifies the inertial mass of Dirac and Weyl particles through the local rapidity field $\psi_g(x)$. This section summarizes the phenomenological domains where such mass renormalization may have observable consequences.

3.1 Weyl particles: geometric mass generation

For a massless (Weyl) fermion, the effective mass induced by the spatial or temporal variation of the rapidity field is

$$m_{\text{geom}}(x)c = \frac{\hbar}{c}\,(\partial_\mu \psi_g)\,u^\mu. \tag{22}$$

This term vanishes in static fields but becomes nonzero wherever $\psi_g(x)$ changes rapidly. Although the effect is extremely small under terrestrial conditions, it may have relevance in extreme astrophysical or cosmological environments:

- **Core–collapse supernovae:** large and time–dependent gravitational fields together with intense neutrino fluxes may produce transient, geometry–induced neutrino masses modifying flavor conversion phases.
- **Binary mergers and gravitational–wave bursts:** during the passage of a strong gravitational wave, $\dot{\psi}_g$ may reach values sufficient to generate sub–eV effective neutrino masses, potentially yielding correlated phase delays between neutrino and GW signals.
- **Early universe:** in epochs of rapid cosmic expansion, geometry–induced masses could transiently alter neutrino decoupling or the effective number of relativistic degrees of freedom N_{eff}.
- **Topological or self–organized rapidity structures:** localized Q_g vortices or spiral inflows may create anisotropic rapidity gradients that act as minute, direction–dependent mass perturbations for passing Weyl fields.

These scenarios provide arenas where the derivative coupling $(\partial_\mu \psi_g)u^\mu$ could lead to small but conceptually distinct signatures beyond the standard model: tiny, time–correlated phase shifts in neutrino oscillations or early–universe relics in N_{eff}.

3.2 Dirac particles: gravitational mass renormalization

For massive fermions the rotor field renormalizes the rest mass as

$$m_{\text{eff}}(x)c = m_0 c \cosh\psi_g(x) + \frac{\hbar}{c}(\partial_\mu \psi_g)\, u^\mu. \tag{23}$$

The two terms lead to distinct phenomenology.

(a) Static redshift—confirmed regime. In stationary gravitational fields the derivative term can be neglected, yielding

$$m_g(x) \simeq m_0\left(1 + \frac{\phi(x)}{c^2}\right),$$

so that all bound energies scale with m_g. This reproduces the universal gravitational redshift of atomic, molecular, and nuclear transitions, now interpreted as a mass–renormalization of the Dirac adjoint rather than a coordinate–time effect. The prediction is consistent with:

- gravitational redshift of optical and Mössbauer transitions,
- comparison of terrestrial and satellite clocks,
- redshift of decay Q–values and particle lifetimes.

(b) Derivative corrections—potential new effects. The second term, $(\hbar/c)(\partial_\mu\psi_g)u^\mu$, introduces a trajectory– and orientation–dependent mass shift. Although exceedingly small in ordinary conditions, it may produce measurable residuals in strong–field or high–precision contexts:

- **Accretion disks and galactic inflows:** spatial variation of $\psi_g(r, \varphi)$ around compact objects can induce tiny, azimuth–dependent shifts of spectral lines (e.g., Fe Kα) beyond GR redshift models.
- **Precision clock networks:** comparison of electronic and nuclear clocks following different trajectories through a gravity gradient could reveal minute, species–dependent deviations from universality.
- **Interferometric tests:** in atom or neutron interferometers the accumulated Compton phase depends on $m_{\text{eff}}c^2/\hbar$; varying ψ_g along the paths introduces a small additional phase proportional to $\int(\partial_\mu\psi_g)u^\mu\, dt$.
- **Strong–field astrophysics:** near neutron stars or black–hole disks, gradients of the rapidity field may generate characteristic residuals in atomic features and in the polarization of emitted radiation.

In summary, the static component of the mass renormalization already accounts for observed gravitational redshifts, while the derivative coupling offers a path to new, extremely small, yet conceptually distinctive, signatures. These may become accessible through future multi–species clock comparisons, high–precision interferometry, or spectroscopy in strong gravitational fields.

4 Geometry from Within: Gravitational Redshift as Dirac Mass Renormalization

A central point of the rotor formulation is that spacetime geometry is not imposed externally on the Dirac equation, but arises *from within* its own algebraic structure once the fixed time axis γ_0 is replaced by the local time direction generated by the rotor field $Q_g(x)$. This provides an intrinsic explanation for the universal gravitational redshift of all bound energies.

Local time direction. In flat space the Dirac adjoint $\bar{\Psi} = \Psi^\dagger \gamma_0$ defines a global inner product with respect to the constant time axis γ_0. When gravity is present, the same role is played by the *locally rotated* timelike direction

$$e_0(x) = Q_g^{-1}(x)\, \gamma_0\, Q_g(x), \tag{24}$$

which acts as the unit normal to the local time slice. The covariant adjoint therefore becomes

$$\bar{\Psi}_g = \Psi^\dagger\, e_0(x) = \Psi^\dagger\, Q_g^{-1} \gamma_0 Q_g. \tag{25}$$

All observables—including energy and current densities—are defined with respect to this locally generated direction.

Projection of the Dirac operator. The curved–space Dirac equation

$$(i\hbar \gamma^\mu D_\mu - m_0 c)\Psi = 0, \qquad D_\mu = \partial_\mu + \tfrac{1}{2} \not{G}_\mu,$$

may be projected onto the local time axis by multiplying on the left by $\bar{\Psi}_g$ and using (25). The resulting energy operator, evaluated along $e_0(x)$, defines the local Hamiltonian

$$i\hbar\, \partial_{t_{\mathrm{loc}}} \Psi = H_g\, \Psi, \qquad H_g = \boldsymbol{\alpha}_g \cdot \boldsymbol{\pi} + \beta_g\, m_0 c^2 + \cdots, \tag{26}$$

where $\boldsymbol{\alpha}_g = Q_g^{-1} \boldsymbol{\alpha} Q_g$ and $\beta_g = Q_g^{-1} \beta Q_g$. For a stationary field ($\partial_t \psi_g = 0$), the local "mass term" in (26) is

$$m_g(x) c^2 = m_0 c^2\, \cosh\psi_g(x), \tag{27}$$

showing that the gravitational field rescales the mass parameter by the local rapidity field ψ_g.

Bound energies and redshift. All bound–state energies scale linearly with m_g. For small ψ_g one finds

$$\frac{\Delta E_n}{E_n} = \frac{\Delta m_g}{m_g} \simeq \frac{\Delta \phi}{c^2},$$

where ϕ is the Newtonian potential related to ψ_g through $\phi \simeq \frac{1}{2} c^2 \psi_g^2$. Hence the observed gravitational redshift of atomic, molecular, and nuclear transitions, $\nu_{\mathrm{obs}}/\nu_{\mathrm{emit}} = 1 + \Delta\phi/c^2$, emerges directly from the local projection of the Dirac Hamiltonian: *it is a mass renormalization in the Dirac operator itself, not a postulated slowing of time.*

Interpretation. In conventional treatments, one introduces a curved metric $g_{00} = -\,(1+2\phi/c^2)$ and computes redshift as the ratio of coordinate times between two spatial positions. In the rotor formalism, by contrast, the metric and its time direction arise internally from $Q_g(x)$. The adjoint (25) automatically "tilts" the local time axis, and the Dirac equation evaluated with respect to that axis produces the redshift factor $\cosh \psi_g$. Thus the geometry of spacetime is encoded algebraically in the adjoint structure of the quantum field.

> *Geometry is not imposed on the Dirac equation; it is projected out from within it. The gravitational redshift is the manifestation of this projection—a local renormalization of the mass term through the rotor field Q_g, rather than an external modification of coordinate time.*

5 One Mechanism, Three Regimes: Geometry from the Adjoint

The substitution of the rotor field $Q_g(x)$ into the Dirac adjoint,

$$\bar{\Psi} \;\longrightarrow\; \bar{\Psi}_g = \Psi^\dagger Q_g^{-1} \gamma_0 Q_g,$$

encodes the complete gravitational phenomenology within the spinor algebra itself. Through the single operation $\gamma_0 \to Q_g^{-1} \gamma_0 Q_g$, the theory passes smoothly from flat spacetime to weak and strong gravitational regimes.

(1) Flat space. For a globally inertial frame $Q_g = \mathbf{1}$, the local time axis reduces to $e_0 = \gamma_0$, and the adjoint returns to its textbook form $\bar{\Psi}_g = \Psi^\dagger \gamma_0$. The Dirac equation then reads

$$(i\hbar\gamma^\mu \partial_\mu - m_0 c)\Psi = 0,$$

with constant rest mass m_0 and no gravitational effects.

(2) Weak curvature: redshift regime. For a slowly varying gravitational field,

$$Q_g(x) = \exp\left[-\frac{1}{2}\psi_g(x)\,\hat{\mathbf{n}}\cdot\boldsymbol{\beta}\right], \qquad |\partial_\mu \psi_g| \ll 1,$$

the local time direction becomes $e_0(x) = Q_g^{-1}\gamma_0 Q_g$ and the effective mass is

$$m_g(x) = m_0 \cosh\psi_g(x) \simeq m_0\left(1 + \frac{\phi(x)}{c^2}\right),$$

where $\phi(x)$ is the Newtonian potential. All bound energies scale with m_g, producing the *universal gravitational redshift* as a *mass renormalization inside the Dirac Hamiltonian.* No external metric or clock postulate is required.

(3) Strong curvature: derivative regime. When curvature gradients are appreciable, the derivative of the rapidity field enters explicitly:

$$m_{\text{eff}}(x)c = m_0 c\ \cosh\psi_g(x) + \frac{\hbar}{c}(\partial_\mu \psi_g)\,u^\mu.$$

The first term reproduces the redshift factor, while the second represents the *high–curvature correction or stress term.* For Weyl fields with $m_0 = 0$, this derivative coupling generates an effective mass entirely from geometry, $m_{\text{geom}}(x) = (\hbar/c^2)\,(\partial_\mu\psi_g)u^\mu$.

Unified interpretation. The same algebraic substitution therefore captures:

(a) the flat–space Dirac theory ($Q_g = \mathbf{1}$),

(b) the weak–field gravitational redshift ($m_g = m_0 \cosh\psi_g$),

(c) and the strong–field/gradient regime (m_{eff}) with curvature–induced stress effects.

In this sense, *gravity, redshift, and curvature corrections all emerge from within the Dirac adjoint itself, through the single rotor insertion $Q_g^{-1}\gamma_0 Q_g$*—a unification of geometry, mass, and quantum dynamics achieved in one stroke.

6 Comparison with Other Unification Approaches

This section contrasts the single-step rotor–adjoint mechanism $\gamma_0 \mapsto Q_g^{-1}\gamma_0 Q_g$ with several major approaches to quantum gravity and unification, using the same coverage criteria: (i) flat-space limit, (ii) weak-field redshift, (iii) strong-field/gradient corrections, (iv) Weyl (massless) sector and possible geometry-induced mass, (v) direct phenomenology at low energies.

Summary Table

Table 1: *
Table A — Coverage (Part 1): Geometry-in-Adjoint, Flat Limit, Redshift Regime

Approach	**Geometry in Dirac adjoint?**	**Flat limit**	**Redshift regime (how obtained)**
This work (Q_g in adjoint)	✓ via $e_0 = Q_g^{-1}\gamma_0 Q_g$	✓ ($Q_g = \mathbf{1}$)	✓ intrinsic: $m_0 \to m_0 \cosh \psi_g$ (adjoint mass renormalization)
GR (tetrad + spin connection)	× (adjoint unchanged)	✓	✓ via metric g_{00} (clock postulate)
Einstein–Cartan (torsion)	×	✓	✓ via metric; torsion does not generate adjoint mass scaling
Scalar–tensor / dilaton	×	✓	(∼) via $m(\Phi)$ rescaling (scalar field), not adjoint geometry
Geometric Algebra / STA	(∼) (rotors as frames; not in adjoint)	✓	(∼) via metric factors; no adjoint mass renormalization
Loop QG / Spin foams	×	✓ (emergent)	(∼) emergent classical limit; no adjoint mechanism
CDT / Causal sets	×	✓ (emergent)	(∼) emergent large-scale redshift; no adjoint mechanism
Asymptotic safety (QEG)	×	✓	(∼) via RG-improved metric; no adjoint mechanism
String theory / Supergravity	× (spinors in higher D; background geometry)	✓	(∼) via warped backgrounds/fluxes; not via adjoint
Noncommutative geometry (Connes)	× (spectral triple; adjoint standard)	✓	(∼) spectral distance effects; redshift not as adjoint mass scaling

Table 2: *

Table B — Coverage (Part 2): Strong/Gradient Regime, Weyl Mass, Low-Energy Phenomenology

Approach	**Strong/Gradient regime (how handled)**	**Weyl mass from geometry?**	**Low-energy phenomenology**
This work (Q_g in adjoint)	✓ via derivative term $(\hbar/c)(\partial_\mu \psi_g)u^\mu$ (operator-level)	✓ (geometry-induced effective mass for Weyl via gradients)	Clock redshift as mass renormalization; unified GE+GM lensing; spinor interferometry
GR (tetrad + spin connection)	✓ via curvature tensors; spin connection	× (massless Weyl remains massless)	Redshift, geodesy, gravitational waves
Einstein–Cartan (torsion)	✓ torsion–spin couplings; strong-field corrections	(∼) axial self-couplings (model dependent), not generic geometric mass	Spin–torsion bounds (lab/astro)
Scalar–tensor / dilaton	(∼) scalar gradients; effective potentials	(∼) possible via $m(\Phi)$, not from adjoint geometry	Varying constants; fifth-force tests; cosmology
Geometric Algebra / STA	✓ formal curvature coverage; no adjoint stress term	× (no intrinsic geometric Weyl mass)	Compact reformulations, visualization
Loop QG / Spin foams	(∼) discrete/spinfoam dynamics; no continuous adjoint term	×	Planck-scale signatures; emergent geometry
CDT / Causal sets	(∼) discreteness corrections; emergent continuum	×	Large-scale spacetime reconstruction
Asymptotic safety (QEG)	✓ RG-improved curvature at strong fields	×	High-energy GR flow; black-hole phenomenology
String theory / Supergravity	✓ strong fields via fluxes/warping/backreaction	(∼) via moduli/Higgs sectors, not adjoint geometry	UV completion; cosmology; model building
Noncommutative geometry (Connes)	(∼) inner fluctuations; spectral action corrections	(∼) via Yukawa structures, not curvature gradients	SM + gravity spectral unification

Key Differences in How Coverage is Achieved

(i) Flat-space limit. All approaches reproduce flat-space quantum theory; in the present framework this is simply $Q_g = \mathbf{1}$ so that $e_0 = \gamma_0$ and $\bar{\Psi}_g = \Psi^\dagger \gamma_0$.

(ii) Weak-field redshift. General relativity accounts for redshift through the metric component g_{00} (clock postulate). By contrast, the rotor–adjoint mechanism produces redshift *intrinsically* as a mass rescaling $m_g = m_0 \cosh \psi_g$ inside the Dirac Hamiltonian; no external time postulate is required. Scalar–tensor models may mimic this via a field-dependent mass $m(\Phi)$, but not via the adjoint's local time projector.

(iii) Strong-field / gradient corrections. In GR and related approaches, strong fields enter via curvature and, if present, torsion; in the present framework they appear already at the operator level through the derivative ("stress") term $(\hbar/c)(\partial_\mu \psi_g)u^\mu$, modifying the local mass seen by the spinor and yielding a direct link to spinor phases and interferometric observables.

(iv) Weyl sector and geometry-induced mass. Most frameworks preserve masslessness of a Weyl field unless additional scalar sectors are introduced (Higgs, dilaton, moduli). Here, the Weyl field acquires an *effective geometric mass* from curvature gradients through the same adjoint mechanism ($m_{\text{geom}} c = (\hbar/c)(\partial_\mu \psi_g)u^\mu$), providing a covariant, spinor-native channel absent from the other programs.

(v) Low-energy phenomenology. GR and metrical approaches reproduce universal redshift and lensing. The rotor–adjoint mechanism reproduces those *and* supplies operator-level predictions: (i) redshift as mass renormalization in precision clocks, (ii) a unified GE+GM lensing split from the same rotor, (iii) principled (albeit tiny) curvature-gradient effects in spinor phases, and (iv) a geometric route to Weyl effective masses in extreme regimes. Other programs (LQG, CDT, asymptotic safety, strings, NCG) target UV completion or structural unification but do not furnish a comparably simple, test-grade, low-energy spinor phenomenology tied to the adjoint.

Conclusion. Whereas most unification approaches place geometry *around* quantum fields (via metrics, connections, or extra scalars), the present framework places geometry *inside* the quantum inner product through $Q_g^{-1}\gamma_0 Q_g$. This single substitution covers the flat limit, weak-field redshift, and strong-field/gradient regimes within one operator, and uniquely endows the Weyl sector with a geometric mass channel—a combination not provided by competing approaches.

7 Conclusion

The analysis developed in this work demonstrates that the gravitational rotor field $Q_g(x)$—inserted directly into the Dirac adjoint $\bar{\Psi}_g = \Psi^\dagger Q_g^{-1}\gamma_0 Q_g$—provides a single, covariant mechanism that unites the description of flat space, gravitational redshift, and strong–field curvature effects within one algebraic operation.

Geometry inside the adjoint. By replacing the fixed time axis of the Dirac theory with the local time direction $e_0 = Q_g^{-1}\gamma_0 Q_g$, geometry enters the quantum inner product itself rather than being imposed externally through the metric. The same operator that defines probability and energy expectation also generates the curved time flow that produces gravitational phenomena. This leads to an intrinsic interpretation of the gravitational redshift as a *mass renormalization* of the Dirac Hamiltonian.

Unified mass law. The effective mass derived from the rotor field,

$$m_{\text{eff}}(x)c = m_0 c \cosh\psi_g(x) + \frac{\hbar}{c}(\partial_\mu \psi_g)u^\mu,$$

reduces to the constant m_0 in flat space, gives $m_g = m_0 \cosh\psi_g$ in weak fields (gravitational redshift regime), and adds a derivative "stress" correction in strong curvature. For $m_0 = 0$ (Weyl fields) the same term yields a geometry–induced effective mass $m_{\text{geom}} = (\hbar/c^2)(\partial_\mu \psi_g)u^\mu$. Hence the adjoint rotor mechanism simultaneously *renormalizes* existing masses and *creates* effective mass for massless spinors in a varying gravitational field.

Consistency with classical limits. The weak–field approximation reproduces the standard exponential redshift $m_g = m_0 e^{\phi/c^2}$, confirming compatibility with Newtonian and general–relativistic predictions. The rotor formulation therefore preserves all verified low–energy limits of GR while giving them an algebraic, spinorial origin.

Phenomenological scope. At laboratory and astrophysical scales the static component of m_g accounts for observed gravitational redshifts. The derivative term is tiny under terrestrial conditions but provides a principled path to new tests: multi–species clock networks, atom or neutron interferometry in gravity gradients, and spectroscopy near compact objects. For Weyl fields, curvature–induced mass generation offers a geometric interpretation of neutrino mass and mixing in high–curvature or early–universe regimes.

Relation to other unification programs. While most approaches place geometry *around* the quantum fields—through metrics, connections, or scalar extensions—the present framework places geometry *inside* the quantum inner product. The single substitution $\gamma_0 \to Q_g^{-1}\gamma_0 Q_g$ covers the flat, weak, and strong gravitational domains within one operator and uniquely endows the Weyl sector with a geometric mass channel. No other current unification scheme provides this direct, low–energy phenomenology at the operator level.

Outlook. Future work should investigate the coupling of Q_g to gauge and Higgs fields, its role in cosmological curvature–volume exchange, and possible observational consequences of the derivative term in extreme gravitational environments. The rotor–adjoint formulation thus offers a compact, testable bridge between quantum mechanics, special relativity, and gravity—a framework in which *mass, curvature, and time flow are different manifestations of the same spinorial geometry.*

References

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