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From Quantum Geometry to Emergent Gravity

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Abstract

We develop a complete geometric framework in which each quantum particle possesses its own private spacetime—a *world-block*—constructed from Fermi–Walker coordinates. The intrinsic spatial metric on each proper-time slice is a dynamical field governed by an action with a universal stiffness constant A_0. A single world-block exhibits *kinematic non-locality*: the metric perturbation at a point depends on the entire wavefunction through an integral relation, while maintaining *dynamic locality* via causal wave equations. This duality captures the essential non-locality of quantum mechanics without violating relativistic causality. When two particles interact, their world-blocks are *stitched* along a common boundary, forming a single *compound world-block* in ordinary four-dimensional spacetime. The stitching imposes local matching conditions that yield a non-separable strain field, providing a geometric account of quantum entanglement. Measurements correspond to fixing boundary conditions on one part of the compound block; the correlated outcome on the distant part is automatically determined by the shared global geometry, not by any superluminal signal. Thus, the apparent non-locality of EPR correlations is explained as a manifestation of geometric connectivity within a single 4D manifold, consistent with Bell's theorem because the geometry itself is non-local. In the continuum limit of many overlapping blocks, coarse-graining restores an effective local description, and Newton's law of universal gravitation emerges exactly, with Newton's constant given by $G = 3c^4/(8\pi A_0)$. The model offers a unified, deterministic, and fully relativistic foundation for quantum mechanics and gravity, without invoking extra dimensions or stochastic elements. Experimental signatures in ultrafast interferometry and possible connections to dark energy are discussed. The framework aligns with recent developments in emergent gravity and provides a concrete geometric realization of spacetime from quantum entanglement.

Keywords: repulsive self-gravity; attractive mutual gravity; kinematic non-locality; entanglement geometry; emergent gravity; universal stiffness; quantum foundations

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1. Introduction

The reconciliation of quantum mechanics with general relativity remains one of the most profound challenges in theoretical physics. A central tension lies in the concept of locality: general relativity is built upon a local, causal spacetime structure, while quantum mechanics exhibits inherently non-local features such as entanglement and the extended nature of wavefunctions.

The philosophical foundations of space and time have long grappled with these issues. Debates between substantivalism and relationism [1] provide essential context for understanding how spacetime might emerge from more fundamental structures. Recent work in quantum foundations [2] has highlighted the need for a clear ontology of the wavefunction, with some authors advocating for wavefunction realism [2] while others examine the historical and physical foundations of hidden variables [3]. The ontological status of the wavefunction continues to spark debate [4], dividing views between those who see it as a tool for knowledge (epistemological) and those who regard it as a real, physical entity (ontological). Schrödinger's 1927 vision of the electron as a "cloud-like" entity already hinted at a non-local description of matter, but the question of how such a cloud could coexist with a local spacetime geometry has remained open.

Collapse models [5] and approaches linking gravity to quantum state reduction suggest that gravity may play a fundamental role in bridging quantum and classical regimes. In particular, Penrose's influential work [5] has long advocated for gravitational state reduction as a possible mechanism for wavefunction collapse. The Schrödinger-Newton equation, originally introduced by Diósi [6] and later developed by Penrose [5], has been extensively studied as a candidate for gravitational self-interaction in quantum systems [7]. Critical analyses by Giulini and Grossardt [7] have examined the regime of validity and experimental prospects for detecting SN-induced effects. In this context, Verrall et al. [8] have explored semiclassical quantum networks in the context of low-energy nucleons, which resonates with the geometric perspective developed here.

Advances in emergent gravity [13–16] suggest that spacetime itself may arise from more fundamental quantum degrees of freedom, with quantum entanglement playing a crucial role [13]. The world-block model developed here provides a concrete realization of these ideas.

Recent work on quantum foundations [9,11,12] has explored various approaches to reconciling quantum non-locality with spacetime structure, including fundamentally classical frameworks for quantum gravity [9] and unified theories of gravity with the Standard Model [10].

In this paper we propose a geometric framework that embraces this tension rather than resolving it by fiat. Each quantum particle is endowed with its own private spacetime—a *world-block* constructed from Fermi–Walker coordinates [18–20] adapted to its world-line. The spatial metric on each proper-time slice is a dynamical field, sourced by the particle's wavefunction and governed by an action principle with a *universal stiffness constant* A_0. This single assumption yields a rich structure:

- A single world-block is **kinematically non-local**: the metric perturbation at a point depends on the entire wavefunction through an integral relation, mirroring the non-locality of quantum mechanics. Yet it remains **dynamically local**: all fields obey causal wave equations, preserving relativistic causality.
- Self-gravity derived from this geometry is **repulsive**, preventing gravitational collapse. This contrasts with the attractive self-gravity in the Schrödinger–Newton equation and is a key feature of the model.
- When two particles interact, their world-blocks are **stitched** along a common boundary, forming a single **compound world-block** in ordinary four-dimensional spacetime. The stitching imposes local matching conditions that yield a non-separable strain field, providing a geometric account of quantum entanglement.
- Measurements correspond to fixing boundary conditions on one part of the compound block; the correlated outcome on the distant part is automatically determined by the shared global geometry, not by any superluminal signal. Thus, the apparent non-locality of EPR correlations is explained as a manifestation of geometric connectivity within a single 4D manifold, and because the geometry itself is non-local, this is consistent with Bell's theorem.
- In the continuum limit of many overlapping blocks, coarse-graining restores an effective local description. Newton's law of universal gravitation emerges exactly, with Newton's constant derived from the universal stiffness via $G = 3c^4/(8\pi A_0)$.

The paper is organised as follows. Section 2 introduces Fermi–Walker coordinates and the world-block concept. Section 3 presents the action with universal stiffness and derives the field equations. Section 4 analyses the non-local structure of a single block, introducing the crucial distinction between kinematic and dynamic (non)locality. Section 5 develops the stitching formalism for two interacting blocks, showing how a compound block encodes entanglement, and discusses the case of arbitrarily distant entangled particles. Section 6 explains the measurement process in terms of boundary conditions. Section 7 demonstrates how the model accounts for single-particle interference, including the double-slit experiment. Section 8 shows how Newtonian gravity emerges from stitching and coarse-graining. Section 9 offers speculative cosmological implications. Section 10 discusses experimental signatures and proposed tests. Section 11 concludes with reflections on the nature of

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wavefunction, spacetime, and reality. Appendices contain detailed derivations of the field equations, stitching conditions, and coarse-graining estimates.

2. Fermi–Walker Coordinates and the World-Block

We begin by constructing a private spacetime for a single particle following a world-line $x^\mu(\tau)$ with proper time τ. In a neighbourhood of this world-line, Fermi–Walker coordinates $(\tau, \vec{x})$ provide a natural coordinate system where the metric takes the form [18–20]:

$$ds^2 = -\left(1 + \frac{a_i x^i}{c^2}\right)^2 d\tau^2 + \delta_{ij} dx^i dx^j + O(|x|^2), \tag{1}$$

where a_i are the components of the proper acceleration. For simplicity, we restrict to geodesic motion ($a_i = 0$) and work to linear order in x. The line element then simplifies to

$$ds^2 = -c^2 d\tau^2 + \delta_{ij} dx^i dx^j. \tag{2}$$

Definition 2.1 (World-block)**.** *The* world-block $\mathcal{M}$ *of a particle is the four-dimensional manifold covered by its Fermi–Walker coordinates* $(\tau, \vec{x})$*. On each constant-*τ *slice, we introduce a dynamical spatial metric*

$$h_{ij}(\tau, \vec{x}) = \delta_{ij} + \varepsilon_{ij}(\tau, \vec{x}), \tag{3}$$

where ε_{ij} *is a small perturbation. The particle's quantum state is described by a wavefunction* $\psi(\tau, \vec{x})$ *normalised as*

$$\int d^3x\, |\psi|^2 = 1. \tag{4}$$

The mass density is $\rho(\tau, \vec{x}) = |\psi(\tau, \vec{x})|^2$.

The world-block thus provides a private spacetime for each particle, with geometry dynamically coupled to its quantum state. The key idea is that this private spacetime is not an auxiliary structure but the fundamental arena in which the particle exists and evolves.

3. Action Principle and Field Equations

We postulate an action for a single world-block, treating ε_{ij} and ψ as dynamical fields on the spatial slice:

$$S = \int d\tau \int d^3x\, [\mathcal{L}_{\rm ge} + \mathcal{L}_m]. \tag{5}$$

The geometric Lagrangian density is quadratic in spatial derivatives of ε_{ij}:

$$\mathcal{L}_{\rm ge} = \frac{A_0}{2}\, \partial_k \varepsilon_{ij}\, \partial^k \varepsilon^{ij}, \tag{6}$$

with indices raised by the flat metric δ^{ij}. The constant A_0 has dimensions $[A_0] = MLT^{-2}$ (energy per unit length) and is postulated to be universal—independent of the particle's mass.

The matter Lagrangian couples ε_{ij} to the wavefunction. For a non-relativistic particle, we take

$$\mathcal{L}_m = \frac{i\hbar}{2}(\psi^* \partial_\tau \psi - \psi \partial_\tau \psi^*) - \frac{\hbar^2}{2m}\delta^{ij}\partial_i \psi^* \partial_j \psi - \frac{mc^2}{2}\varepsilon\, |\psi|^2, \tag{7}$$

where $\varepsilon = \delta^{ij}\varepsilon_{ij}$ is the trace of ε_{ij}. The coupling term $\varepsilon|\psi|^2$ is the simplest scalar that respects spatial isotropy. The factor mc^2 ensures correct dimensions and will be justified by comparison with gravity.

Remark 3.1. *We have omitted an external potential* $V(\vec{x})$ *for brevity; it can be restored straightforwardly.*

3.1. Field Equations

Varying with respect to ε^{ij} gives

$$A_0\,\partial^k\partial_k\varepsilon_{ij} = -\frac{mc^2}{2}|\psi|^2\delta_{ij}, \tag{8}$$

or equivalently,

$$\nabla^2\varepsilon_{ij} = -\frac{mc^2}{2A_0}\rho\delta_{ij}. \tag{9}$$

Taking the trace yields

$$\nabla^2\varepsilon = -\frac{3mc^2}{2A_0}\rho. \tag{10}$$

Varying with respect to ψ^* gives the Schrödinger equation

$$i\hbar\partial_\tau\psi = -\frac{\hbar^2}{2m}\nabla^2\psi - \frac{mc^2}{2}\varepsilon\psi. \tag{11}$$

The system is closed: ψ sources ε through (9), and ε feeds back into the evolution of ψ through (11). A detailed derivation of these field equations via variational calculus is provided in Appendix A.

4. Kinematic Non-Locality of a Single World-Block

4.1. Gravitational Potential and Self-Gravity

From the trace equation (10) we define the gravitational potential $\Phi = c^2\varepsilon$ satisfying

$$\nabla^2\Phi = \frac{3c^4}{2A_0}\rho_m, \qquad \rho_m = m\rho. \tag{12}$$

Comparing with the Newton–Poisson equation $\nabla^2\Phi = 4\pi G\rho_m$ identifies the effective self-gravity coupling:

$$4\pi G_{\text{self}} = \frac{3c^4}{2A_0} \quad\Longrightarrow\quad G_{\text{self}} = \frac{3c^4}{8\pi A_0}. \tag{13}$$

Requiring this to match the observed Newton constant G fixes the universal stiffness:

$$\boxed{A_0 = \frac{3c^4}{8\pi G}}. \tag{14}$$

4.2. Kinematic Non-Locality

The solution for ε (ignoring the harmonic part) is

$$\varepsilon(\vec{x}) = -\frac{3mc^2}{2A_0}\int d^3y\,\frac{\rho(\vec{y})}{4\pi|\vec{x}-\vec{y}|}. \tag{15}$$

This expresses the metric perturbation at $\vec{x}$ as an integral over the entire wavefunction—a manifestly non-local relation.

Definition 4.1 (Kinematic non-locality). *A field theory exhibits* kinematic non-locality *if the value of a field at a point depends on the source distribution at distant points through an integral relation, even though the field equation itself is local.*

In our case, $\varepsilon(\vec{x})$ satisfies the local Poisson equation $\nabla^2\varepsilon = \text{source}(\vec{x})$, but its solution (15) expresses $\varepsilon(\vec{x})$ as an integral over all sources. This is the same type of non-locality present in Newtonian gravity or electrostatics.

Definition 4.2 (Dynamic locality)**.** *A theory is* dynamically local *if all fields obey local differential equations (wave equations) that guarantee causal propagation of disturbances.*

Despite the kinematic non-locality, the full time-dependent system is dynamically local. The field equation (8) is a wave equation when time derivatives are included; disturbances propagate at finite speed along the light cones of the private spacetime.

Remark 4.3. *This duality is essential: the world-block captures the non-local aspects of quantum mechanics (the integral relation) while maintaining the causal structure required by relativity. It mirrors the structure of classical field theories, where potentials are kinematically non-local but dynamics are local.*

Substituting (15) into the Schrödinger equation (11) yields the non-local integro-differential equation

$$i\hbar\partial_\tau\psi = -\frac{\hbar^2}{2m}\nabla^2\psi + \frac{3m^2c^4}{2A_0}\int d^3y\,\frac{|\psi(\vec{y})|^2}{4\pi|\vec{x}-\vec{y}|}\,\psi(\vec{x}). \tag{16}$$

With $A_0 = 3c^4/(8\pi G)$, this simplifies to

$$\boxed{i\hbar\partial_\tau\psi = -\frac{\hbar^2}{2m}\nabla^2\psi + Gm^2\int d^3y\,\frac{|\psi(\vec{y})|^2}{|\vec{x}-\vec{y}|}\,\psi(\vec{x})}. \tag{17}$$

The positive sign indicates that self-gravity is **repulsive**. For a point-like concentration, the force derived from this term is outward, opposing collapse. This repulsive self-gravity is a direct consequence of the wavefunction sourcing its own geometry and is a key prediction of the model.

Remark 4.4 (Connection to other approaches)**.** *Equation* (17) *shares structural similarities with recent proposals for fundamentally classical frameworks for quantum gravity [9,12]. The repulsive sign distinguishes our model from the attractive Schrödinger–Newton equation and ensures stability.*

5. Stitching Two World-Blocks: The Compound Block

We now consider two particles A and B that interact. Before interaction, they possess independent world-blocks $\mathcal{M}_A$ and $\mathcal{M}_B$ with strain fields $\varepsilon_{ij}^{(A)}$ and $\varepsilon_{ij}^{(B)}$. The interaction creates a *compound world-block* $\mathcal{M}_{AB}$ formed by stitching the two original blocks along a common boundary Γ_{AB}.

Definition 5.1 (Stitching)**.** *Two world-blocks $\mathcal{M}_A$ and $\mathcal{M}_B$ are* stitched *along a spacelike hypersurface Γ_{AB} if the following matching conditions hold on Γ_{AB}:*

$$\varepsilon_{ij}^{(A)}(\vec{x}) = \varepsilon_{ij}^{(B)}(\vec{x}), \tag{18}$$

$$n^k\partial_k\varepsilon_{ij}^{(A)}(\vec{x}) = n^k\partial_k\varepsilon_{ij}^{(B)}(\vec{x}), \tag{19}$$

where $\vec{n}$ is the unit normal to Γ_{AB}. These conditions ensure that the metric and its extrinsic curvature are continuous across the boundary.

The matching conditions (18)–(19) are *local*: they relate fields at coincident points on Γ_{AB}. They follow from requiring that the action be stationary under variations that preserve the boundary.

The total action for the compound block is the sum of the individual actions plus a boundary term that enforces the matching conditions:

$$S_{AB} = S_A + S_B + S_{\text{boundary}}. \tag{20}$$

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Explicitly,

$$S_{\text{boundary}} = \frac{A_0}{2} \int_{\Gamma_{AB}} d^3\xi \, \sqrt{h} \, n^k \left(\varepsilon_{ij}^{(A)} \partial_k \varepsilon^{ij\,(B)} - \varepsilon_{ij}^{(B)} \partial_k \varepsilon^{ij\,(A)} \right), \tag{21}$$

where ξ^a are coordinates on Γ_{AB} and h is the induced metric. This term is constructed so that variation with respect to the fields on Γ_{AB} yields the matching conditions.

5.1. Non-Separability of the Strain Field

On the compound block $\mathcal{M}_{AB}$, the strain field $\varepsilon_{ij}^{(\text{comp})}$ satisfies the same local field equation (9) everywhere, but with a source that is the sum of the two densities:

$$\nabla^2 \varepsilon_{ij}^{(\text{comp})}(\vec{x}) = -\frac{mc^2}{2A_0} \left(\rho_A(\vec{x}) + \rho_B(\vec{x}) \right) \delta_{ij}. \tag{22}$$

However, due to the matching conditions, the solution on $\mathcal{M}_{AB}$ is **not** simply the sum of the individual solutions:

$$\varepsilon_{ij}^{(\text{comp})} \neq \varepsilon_{ij}^{(A)} + \varepsilon_{ij}^{(B)}. \tag{23}$$

This *geometric non-separability* is the precise analogue of quantum entanglement. The two particles now share a single, extended piece of spacetime.

Proposition 5.2 (Geometric entanglement)**.** *Let ψ_A and ψ_B be the wavefunctions of two particles that have interacted and been stitched into a compound block $\mathcal{M}_{AB}$. The total state is described by a strain field $\varepsilon_{ij}^{(\text{comp})}$ on $\mathcal{M}_{AB}$ that does not factorise as a sum of independent fields. This non-separability encodes the same correlations as the entangled wavefunction $\Psi(\vec{x}_A, \vec{x}_B)$ in standard quantum mechanics.*

5.2. Entanglement of Arbitrarily Distant Particles

The stitching mechanism operates at the moment of interaction, within the common past light cone of the two particles. Once the compound block is formed, it remains a single connected 4D manifold regardless of the subsequent spatial separation of the particles. The matching conditions (18)–(19) impose global constraints on the solution of the field equations, linking the strain field in region A to that in region B. Consequently, even when the particles are light-years apart, their individual world-blocks remain geometrically coupled through the shared boundary conditions.

No signal travels between them after separation; the correlations are encoded in the global structure of the compound block from the outset. This explains why entanglement persists over arbitrarily large distances without violating relativistic causality. The apparent non-locality of quantum mechanics is thus a manifestation of the global connectivity of a single 4D geometry, not of any superluminal influence.

Remark 5.3. *This geometric interpretation of entanglement resonates with the idea that spacetime is built up from quantum entanglement [13] and with recent developments in holography and AdS/CFT where entanglement structure determines spacetime geometry.*

6. Measurement as Boundary Condition

In the compound world-block model, a measurement performed on one particle corresponds to fixing a boundary condition on a local region of $\mathcal{M}_{AB}$. Because the entire geometry is a single connected manifold, this automatically determines the boundary conditions on the correlated distant region.

Definition 6.1 (Measurement slice)**.** *A measurement of the position of particle A is modelled by choosing a spacelike slice Σ_A in $\mathcal{M}_{AB}$ that intersects the world-block of particle A. On this slice, we impose a boundary condition that selects a particular eigenvalue of the position operator. This is implemented by fixing the value of ψ_A on Σ_A (or, more rigorously, by a projection operator in the path integral).*

Because $\mathcal{M}_{AB}$ is a single geometric object, the boundary condition on Σ_A determines via the field equations, the field values on any other slice Σ_B correlated with A. In particular, the outcome of a measurement on particle B is uniquely determined by the geometry and the boundary condition on A.

Remark 6.2 (No hidden variables)**.** *The correlation between measurement outcomes is not due to any pre-existing local property (hidden variable) of each particle individually. Rather, it is encoded in the global, non-local geometry of the compound block. This global structure is a single entity that spans the entire spacetime region containing both particles. When a measurement is performed on one part, the outcome on the distant part is a consequence of the consistency of the global solution, not of any local signal. This is fully compatible with Bell's theorem, which rules out local hidden variable theories, but does not rule out theories with non-local global structures such as the compound world-block. The geometry itself is non-local in the sense that it connects spacelike separated regions, and this non-locality is exactly what quantum mechanics requires.*

A measurement performed on one particle corresponds to specifying a boundary condition on one local region of the joint world–block. Because the underlying geometry is common, this simultaneously fixes the correlated boundary on the distant region. No signal travels between the particles; rather, both outcomes are consistent sections of the same four–dimensional geometry. The two particles share a single, extended piece of spacetime—a compound world-block—whose internal curvature encodes the same correlation structure that appears in the wavefunction. The apparently instantaneous correlations of the EPR experiment therefore arise from the *non-separable geometry* of this joint block, not from superluminal influences. All interactions responsible for the shared geometry occur within the common past light cone at the creation event. After separation, each measurement acts locally within its branch of the compound block; the correlations merely reflect the global constraints of that four–dimensional structure. Thus the world–block model reproduces the observed quantum nonlocality of entangled systems while remaining fully compatible with special relativity.

7. Interference as Geometric Superposition

Interference phenomena such as the double-slit experiment arise naturally in the world-block framework. A single particle corresponds to an extended world-block whose strain field $\varepsilon_{ij}(\mathbf{x})$ obeys the linear field equation:

$$A_0\,\nabla^2\varepsilon_{ij} = -\tfrac{1}{2}mc^2\rho\,\delta_{ij}, \tag{24}$$

with boundary conditions defined by the experimental apparatus.

7.1. Propagation Through the Slits

As the world–block evolves, its strain field spreads and passes through both slits of the barrier. Each slit defines a distinct portion $\varepsilon_{ij}^{(1)}$ and $\varepsilon_{ij}^{(2)}$ of the same continuous world–block. Behind the barrier, the total field is the superposition

$$\varepsilon_{ij} = \varepsilon_{ij}^{(1)} + \varepsilon_{ij}^{(2)}, \tag{25}$$

because the underlying differential equations are linear.

7.2. Formation of the Interference Pattern

On the detection screen, the observable intensity corresponds to the local elastic energy density $u(\mathbf{x}) = A_0\,\partial_k\varepsilon_{ij}\,\partial^k\varepsilon^{ij}$, so that

$$I(\mathbf{x}) \propto |\varepsilon_{ij}^{(1)} + \varepsilon_{ij}^{(2)}|^2 = |\varepsilon^{(1)}|^2 + |\varepsilon^{(2)}|^2 + 2\,\mathrm{Re}(\varepsilon^{(1)*}\varepsilon^{(2)}). \tag{26}$$

The cross–term produces the familiar interference fringes, exactly as in quantum mechanics.

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7.3. Detection as Geometric Stitching

When the particle is detected, the corresponding region of the compound geometry between the world–block of the particle and that of the detector becomes stitched together . This localises the intersection point but does not imply any instantaneous change of the global geometry; the probability for each point of impact is already encoded in the interference pattern of the block's strain field.

The double-slit experiment therefore needs no additional "wave-particle duality" hypothesis in the world–block picture. Each particle's wavefunction *is* its extended spacetime geometry, and interference arises from the linear superposition of that geometry through multiple boundaries within ordinary four-dimensional spacetime.

Remark 7.1. *This interpretation resonates with the many-interacting-worlds approach of Hall, Deckert, and Wiseman [21], where interference arises from a universal repulsive force between an ensemble of worlds. In our model, a single world-block with a non-local self-interaction plays an analogous role, but without invoking multiple worlds.*

7.4. Comparison with Experimental Observations

Experiments with electrons, neutrons and large molecules have confirmed that interference patterns accumulate one particle at a time [22–25]. The world-block model accounts for this by assigning to each particle its own private spacetime, whose geometry determines the probability distribution. The non--local coupling ensures that each particle "knows about" both slits through its own world–block's spatial extent. The particle's private spacetime has a structure that connects the two slits; this structure determines detection probabilities. Thus, the world-block model provides a deterministic, geometric account of particle interference, fully consistent with experimental observations.

8. Emergence of Newtonian Gravity from Stitching

8.1. Superposition of Many Blocks

Consider a region of space containing N world-blocks with masses m_a and densities $\rho_a(\vec{x})$, $a = 1, \ldots, N$. When these blocks are stitched together, the total strain field satisfies

$$\nabla^2 \varepsilon_{ij}^{(\text{tot})}(\vec{x}) = -\frac{c^2}{2A_0} \sum_{a=1}^{N} m_a \rho_a(\vec{x})\, \delta_{ij}. \tag{27}$$

In the continuum limit, we define the total mass density

$$\rho_{\text{tot}}(\vec{x}) = \sum_a m_a \rho_a(\vec{x}), \tag{28}$$

which we assume to be a slowly varying function on scales larger than the typical block size.

Theorem 8.1 (Emergence of locality)**.** *In the limit where the number of blocks $N \to \infty$ and the individual block sizes $\ell \to 0$ such that $\rho_{\text{tot}}(\vec{x})$ remains finite and smooth, the coarse-grained strain field $\bar{\varepsilon}_{ij}(\vec{x})$ satisfies the local Poisson equation*

$$\nabla^2 \bar{\varepsilon}_{ij}(\vec{x}) = -\frac{c^2}{2A_0} \rho_{\text{tot}}(\vec{x}) \delta_{ij} + O(\ell/L), \tag{29}$$

where L is the coarse-graining scale. The error vanishes in the continuum limit $\ell/L \to 0$.

Proof. Define the coarse-grained fields by averaging over a ball of radius $L \gg \ell$:

$$\bar{\varepsilon}_{ij}(\boldsymbol{x}) = \frac{1}{V_L} \int_{|\boldsymbol{x}'-\boldsymbol{x}|<L} \varepsilon_{ij}^{(\text{tot})}(\boldsymbol{x}')\, d^3x', \tag{30}$$

$$\bar{\rho}_{\text{tot}}(\boldsymbol{x}) = \frac{1}{V_L} \int_{|\boldsymbol{x}'-\boldsymbol{x}|<L} \rho_{\text{tot}}(\boldsymbol{x}')\, d^3x'. \tag{31}$$

Applying the Laplacian to $\bar{\varepsilon}_{ij}$ and using linearity,

$$\nabla^2 \bar{\varepsilon}_{ij}(\boldsymbol{x}) = \frac{1}{V_L} \int_{|\boldsymbol{x}'-\boldsymbol{x}|<L} \nabla^2 \varepsilon_{ij}^{(\mathrm{tot})}(\boldsymbol{x}')\, d^3x' = -\frac{c^2}{2A_0} \bar{\rho}_{\mathrm{tot}}(\boldsymbol{x}) \delta_{ij}, \tag{32}$$

exactly. The integral relation (15) becomes approximately local because the Green function $1/|\boldsymbol{x}-\boldsymbol{y}|$ can be expanded in a Taylor series around $\boldsymbol{y} = \boldsymbol{x}$; the leading term gives the local expression, and higher-order terms are suppressed by powers of ℓ/L. A rigorous error estimate is provided in Appendix C. □

8.2. Derivation of Newton's Law

Define the gravitational potential $\Phi = c^2\bar{\varepsilon}$ (taking the trace). The coarse-grained potential satisfies

$$\nabla^2 \Phi(\vec{x}) = \frac{3c^4}{2A_0} \bar{\rho}_{\mathrm{tot}}(\vec{x}) = 4\pi G \bar{\rho}_{\mathrm{tot}}(\vec{x}), \tag{33}$$

using $A_0 = 3c^4/(8\pi G)$. For two point masses m_A and m_B located at $\vec{X}_A$ and $\vec{X}_B$, the solution is

$$\Phi(\vec{x}) = -G\frac{m_A}{|\vec{x}-\vec{X}_A|} - G\frac{m_B}{|\vec{x}-\vec{X}_B|}. \tag{34}$$

The interaction energy is obtained by integrating the mass density of B in the potential of A:

$$U_{AB} = \int \rho_B(\vec{x}) \Phi_A(\vec{x})\, d^3x = -\frac{G m_A m_B}{R_{AB}}, \tag{35}$$

where $R_{AB} = |\vec{X}_A - \vec{X}_B|$. Thus, Newton's law of universal gravitation emerges exactly from the stitching of many world-blocks.

Corollary 8.2. *The universal stiffness A_0 is the fundamental constant from which Newton's constant is derived: $G = 3c^4/(8\pi A_0)$. No free parameters remain.*

9. Cosmological Implications

The universal stiffness A_0 also has implications for cosmology. Treating the vacuum as a collection of virtual world-blocks, one can derive an effective cosmological constant from the harmonic part of the strain field that remains after stitching all blocks. In the absence of sources, the field equation $\nabla^2\varepsilon_{ij} = 0$ admits constant solutions $\varepsilon_{ij} = \Phi_H \delta_{ij}$, where Φ_H is a constant harmonic field. This field contributes an energy density

$$\rho_{\mathrm{vac}} = \frac{A_0}{2}(\nabla\varepsilon)^2 + \text{boundary terms} \sim \frac{c^4}{8\pi G}\Lambda, \tag{36}$$

where Λ is an effective cosmological constant. Dimensional analysis suggests that the magnitude of Φ_H is set by the largest scale in the problem, namely the Hubble radius $R_H = c/H$:

$$\Phi_H \sim \frac{c^2}{R_H^2} \sim H^2. \tag{37}$$

This leads to a vacuum energy density

$$\rho_{\mathrm{vac}} \sim \frac{c^4}{8\pi G} H^2 = \frac{3H^2}{8\pi G} \cdot \frac{c^2}{3} \sim \rho_{\mathrm{crit}}, \tag{38}$$

where $\rho_{\mathrm{crit}} = 3H^2/(8\pi G)$ is the critical density. Thus, the model naturally produces a vacuum energy of order the observed dark energy density, without fine-tuning. This speculative connection deserves

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further investigation and may provide a geometric explanation for the smallness of the cosmological constant.

Remark 9.1. *The idea that the cosmological constant arises from boundary conditions on a fundamental field has parallels in emergent gravity scenarios [15,17] and in some interpretations of the holographic principle [13]. A more detailed analysis would require a full relativistic treatment of the stitching of world-blocks on cosmological scales, which is beyond the scope of the present paper.*

10. Experimental Signatures

The compound world-block model makes several testable predictions, particularly in the realm of precision interferometry with massive particles.

10.1. Deviations from Free Evolution

Equation (17) predicts a deviation from the free Schrödinger evolution for narrow wave packets. For a particle of mass m and wave packet width σ, the self-gravity term becomes significant when

$$\frac{Gm^2}{\sigma} \sim \frac{\hbar^2}{m\sigma^2} \quad \Longrightarrow \quad \sigma \sim \frac{\hbar^2}{Gm^3}. \tag{39}$$

For a proton ($m \approx 1.67 \times 10^{-27}$ kg), this scale is $\sigma \sim 10^{-14}$ m, which is within reach of modern interferometry techniques. Ultrafast laser interferometry with massive molecules or clusters could detect the phase shift induced by the self-gravity term [23–25].

10.2. Entanglement and Non-Locality

The geometric account of entanglement as non-separability of a compound block implies that correlations between entangled particles are encoded in the shared geometry from the moment of interaction. This suggests that any attempt to distinguish the compound block model from standard quantum mechanics would require probing the geometric structure itself, perhaps through experiments that test the gravitational field generated by entangled superpositions [26,27]. Recent proposals for testing the quantum nature of gravity using entangled massive particles [26,27] could indirectly probe the stitching mechanism.

10.3. Macroscopic Superpositions

For masses approaching the Planck scale, the self-gravity term becomes comparable to quantum kinetic energy. While such masses are far beyond current experimental capabilities, future advances in levitated optomechanics [28] might one day test the crossover regime. In the meantime, experiments with massive molecules (up to 10^4 amu) can place upper bounds on the strength of any hypothetical gravitational self-interaction [25,29].

10.4. Cosmological and Astrophysical Tests

The prediction that the vacuum energy density is of order the critical density could be tested by more precise measurements of the equation of state of dark energy. If the harmonic field Φ_H varies on cosmological timescales, it might leave imprints on the cosmic microwave background or large-scale structure [17]. Astrophysical observations of neutron stars or white dwarfs could also constrain any deviation from Newtonian gravity at short distances [30].

11. Conclusion and Outlook

We have presented a geometric framework in which the wavefunction of a quantum particle is realised as the metric of a private spacetime—the world-block. This model offers a unified, deterministic, and fully relativistic foundation for quantum mechanics and gravity. The key insights are:

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- A single world-block exhibits kinematic non-locality: the metric perturbation at a point depends on the entire wavefunction via an integral relation, yet the dynamics remain locally causal. This duality captures the non-local essence of quantum mechanics while preserving relativistic causality.
- The repulsive nature of self-gravity, arising from the universal stiffness A_0, prevents gravitational collapse and naturally explains the spreading of wave packets. This distinguishes the model from the attractive Schrödinger–Newton equation and ensures stability.
- When particles interact, their world-blocks are stitched into a compound block through local matching conditions, yielding a non-separable strain field that geometrically encodes entanglement. The stitching occurs within the common past light cone, and the resulting global structure remains connected regardless of spatial separation, explaining the persistence of entanglement over arbitrarily large distances.
- Measurements are modelled as boundary conditions on the compound block; the correlation between outcomes follows from the global consistency of the geometry, not from any superluminal signal. This is consistent with Bell's theorem because the geometry itself is non-local.
- The model accounts for single-particle interference, such as in the double-slit experiment, through the non-local integral term in the Schrödinger equation, which couples spatially separated components of the wavefunction.
- In the continuum limit of many overlapping blocks, coarse-graining restores an effective local description, and Newton's law of universal gravitation emerges exactly, with $G = 3c^4/(8\pi A_0)$.
- The cosmological constant may find a natural explanation as a harmonic mode of the stitched vacuum, with magnitude set by the Hubble scale.
- Experimental signatures in precision interferometry offer opportunities to test the model's predictions.

Future work will extend the model to include spin, electromagnetic interactions, and a fully covariant formulation. The stitching formalism for many-body systems and the statistical mechanics of stitched blocks may illuminate the emergence of thermodynamics and the arrow of time. The connection to cosmology and dark energy also merits deeper investigation.

In summary, the compound world-block model provides a coherent geometric picture in which quantum non-locality, entanglement, interference, and gravity all emerge from a single underlying structure. It offers a fresh perspective on the oldest questions in physics and opens new avenues for theoretical and experimental exploration.

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Appendix A. Variational Derivation of the Field Equations

We provide a detailed derivation of the field equations from the action principle. The total action for a single world-block is

$$S = \int d\tau \int d^3x \left[\frac{A_0}{2} \partial_k \varepsilon_{ij} \partial^k \varepsilon^{ij} + \frac{i\hbar}{2} (\psi^* \partial_\tau \psi - \psi \partial_\tau \psi^*) - \frac{\hbar^2}{2m} \partial_i \psi^* \partial^i \psi - \frac{mc^2}{2} \varepsilon |\psi|^2 \right]. \tag{A1}$$

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We treat ε_{ij} and ψ as independent fields, with ψ^* as the complex conjugate of ψ.

Appendix A.1. Variation with Respect to ε^{ij}

Consider a variation $\delta\varepsilon_{ij}$. The geometric part of the action gives

$$\delta S_{\text{ge}} = A_0 \int d\tau d^3x\, \partial_k \varepsilon_{ij} \partial^k \delta\varepsilon^{ij}. \tag{A2}$$

Integrating by parts in space (assuming boundary terms vanish at infinity or are cancelled by appropriate boundary conditions) yields

$$\delta S_{\text{ge}} = -A_0 \int d\tau d^3x\, \partial^k \partial_k \varepsilon_{ij} \delta\varepsilon^{ij}. \tag{A3}$$

The matter part contributes

$$\delta S_m = -\frac{mc^2}{2} \int d\tau d^3x\, |\psi|^2 \delta\varepsilon, \tag{A4}$$

where $\delta\varepsilon = \delta^{ij}\delta\varepsilon_{ij}$. Combining these, the principle $\delta S = 0$ for arbitrary $\delta\varepsilon_{ij}$ gives

$$-A_0 \partial^k \partial_k \varepsilon_{ij} \delta\varepsilon^{ij} - \frac{mc^2}{2} |\psi|^2 \delta^{ij} \delta\varepsilon_{ij} = 0, \tag{A5}$$

which implies

$$A_0 \nabla^2 \varepsilon_{ij} + \frac{mc^2}{2} |\psi|^2 \delta_{ij} = 0, \tag{A6}$$

or equivalently Eq. (8).

Appendix A.2. Variation with Respect to ψ^*

Treating ψ and ψ^* as independent, vary with respect to ψ^*. The kinetic term gives

$$\delta S_{\text{kin}} = \int d\tau d^3x \left[\frac{i\hbar}{2} (\delta\psi^* \partial_\tau \psi - \psi \partial_\tau \delta\psi^*) \right]. \tag{A7}$$

Integrating the second term by parts in time (assuming boundary terms vanish at initial and final times) yields

$$-\frac{i\hbar}{2} \int d\tau d^3x\, \partial_\tau \psi \delta\psi^*. \tag{A8}$$

Thus the total kinetic variation becomes

$$\delta S_{\text{kin}} = i\hbar \int d\tau d^3x\, \delta\psi^* \partial_\tau \psi. \tag{A9}$$

The gradient term contributes

$$\delta S_{\text{grad}} = -\frac{\hbar^2}{2m} \int d\tau d^3x\, \partial_i \psi^* \partial^i \delta\psi = \frac{\hbar^2}{2m} \int d\tau d^3x\, \nabla^2 \psi^* \delta\psi, \tag{A10}$$

after integration by parts. The coupling term gives

$$\delta S_{\text{coup}} = -\frac{mc^2}{2} \int d\tau d^3x\, \varepsilon \psi \delta\psi^*. \tag{A11}$$

Setting the total variation to zero for arbitrary $\delta\psi^*$ yields

$$i\hbar \partial_\tau \psi = -\frac{\hbar^2}{2m} \nabla^2 \psi - \frac{mc^2}{2} \varepsilon \psi, \tag{A12}$$

which is Eq. (11).

Appendix B. Derivation of the Stitching Conditions and Boundary Term

We derive the matching conditions for two blocks A and B meeting at a common boundary Γ. The total action is $S_A + S_B$, and we require that the variation vanish under arbitrary variations that preserve the boundary but allow the fields on either side to vary independently. The variation of each bulk action produces a boundary term:

$$\delta S_A = (\text{bulk}) + \frac{A_0}{2}\int_\Gamma d^3\xi\,\sqrt{h}\,n^k\partial_k\varepsilon_{ij}^{(A)}\delta\varepsilon^{ij\,(A)}, \tag{A13}$$

and similarly for S_B with a sign change because the outward normal for B is opposite to that for A. To cancel these boundary variations, we add a boundary term

$$S_{\text{bdry}} = \frac{A_0}{2}\int_\Gamma d^3\xi\,\sqrt{h}\,n^k\left(\varepsilon_{ij}^{(A)}\partial_k\varepsilon^{ij\,(B)} - \varepsilon_{ij}^{(B)}\partial_k\varepsilon^{ij\,(A)}\right). \tag{A14}$$

Varying S_{bdry} gives terms proportional to $\delta\varepsilon_{ij}^{(A)}$ and $\delta\varepsilon_{ij}^{(B)}$ on the boundary. The condition that the total variation vanish for arbitrary independent variations yields

$$n^k\partial_k\varepsilon_{ij}^{(A)} = n^k\partial_k\varepsilon_{ij}^{(B)}, \tag{A15}$$

$$\varepsilon_{ij}^{(A)} = \varepsilon_{ij}^{(B)}, \tag{A16}$$

which are precisely the matching conditions (18) and (19). Thus, the boundary term ensures continuity of the metric and its normal derivative across Γ.

Appendix C. Coarse-Graining Error Estimate

We provide a rigorous estimate of the error in approximating the integral relation by a local differential equation. Let $\rho(x)$ be a smooth source and $\varepsilon(x)$ the solution of $\nabla^2\varepsilon = \kappa\rho$ with $\kappa = 3c^4/(2A_0)$. The coarse-grained fields are defined as

$$\bar{\rho}(\boldsymbol{x}) = \frac{1}{V_L}\int_{B_L(\boldsymbol{x})}\rho(\boldsymbol{y})\,d^3y, \tag{A17}$$

$$\bar{\varepsilon}(\boldsymbol{x}) = \frac{1}{V_L}\int_{B_L(\boldsymbol{x})}\varepsilon(\boldsymbol{y})\,d^3y. \tag{A18}$$

As shown in the main text, $\nabla^2\bar{\varepsilon} = \kappa\bar{\rho}$ exactly.

Now consider the integral representation

$$\bar{\varepsilon}(\boldsymbol{x}) = -\frac{\kappa}{4\pi}\frac{1}{V_L}\int_{B_L(\boldsymbol{x})} d^3y\int d^3z\,\frac{\rho(\boldsymbol{z})}{|\boldsymbol{y}-\boldsymbol{z}|}. \tag{A19}$$

Swap the order of integration and change variables $\boldsymbol{y} = \boldsymbol{x} + \boldsymbol{u}$ with $|\boldsymbol{u}| < L$:

$$\bar{\varepsilon}(\boldsymbol{x}) = -\frac{\kappa}{4\pi}\int d^3z\,\rho(\boldsymbol{z})\left[\frac{1}{V_L}\int_{|\boldsymbol{u}|<L}\frac{d^3u}{|\boldsymbol{x}+\boldsymbol{u}-\boldsymbol{z}|}\right]. \tag{A20}$$

The bracket is the average of the Green function over a ball of radius L. For $|\boldsymbol{x}-\boldsymbol{z}| \gg L$, we can expand

$$\frac{1}{|\boldsymbol{x}+\boldsymbol{u}-\boldsymbol{z}|} = \frac{1}{|\boldsymbol{x}-\boldsymbol{z}|} + \frac{(\boldsymbol{x}-\boldsymbol{z})\cdot\boldsymbol{u}}{|\boldsymbol{x}-\boldsymbol{z}|^3} + O\left(\frac{L^2}{|\boldsymbol{x}-\boldsymbol{z}|^3}\right). \tag{A21}$$

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The linear term averages to zero by symmetry, so the leading correction is of order $L^2/|\boldsymbol{x}-\boldsymbol{z}|^3$. For $|\boldsymbol{x}-\boldsymbol{z}| \lesssim L$, the source ρ varies slowly, and we can approximate it by its value at $\boldsymbol{x}$. A Taylor expansion of ρ around $\boldsymbol{x}$ gives

$$\int d^3z\,\rho(\boldsymbol{z})\frac{1}{|\boldsymbol{x}+\boldsymbol{u}-\boldsymbol{z}|} = \rho(\boldsymbol{x})\int d^3z\,\frac{1}{|\boldsymbol{x}+\boldsymbol{u}-\boldsymbol{z}|} + \partial_i\rho(\boldsymbol{x})\int d^3z\,(z^i-x^i)\frac{1}{|\boldsymbol{x}+\boldsymbol{u}-\boldsymbol{z}|} + \cdots. \tag{A22}$$

The first term, after averaging over $\boldsymbol{u}$, yields a constant (the average potential of a uniform sphere), which can be absorbed into a redefinition of $\bar{\varepsilon}$. The gradient term averages to zero. The error in approximating the full integral by $\kappa\int d^3z\,\rho(\boldsymbol{z})/|\boldsymbol{x}-\boldsymbol{z}|$ is therefore of order ℓ/L, where ℓ is the scale of variation of ρ (the block size). In the continuum limit $\ell/L \to 0$, the error vanishes.

Appendix D. Comparison with the Schrödinger–Newton Equation

The Schrödinger–Newton (SN) equation is usually written as

$$i\hbar\partial_t\psi = -\frac{\hbar^2}{2m}\nabla^2\psi - Gm^2\int d^3y\,\frac{|\psi(\boldsymbol{y})|^2}{|\boldsymbol{x}-\boldsymbol{y}|}\,\psi(\boldsymbol{x}), \tag{A23}$$

with a negative sign indicating attractive self-gravity. Our Eq. (17) differs by the sign of the integral term: it is positive (repulsive). This difference arises from the trace of the stress-energy tensor in our coupling. In the non-relativistic limit, the spatial stress-energy tensor for a perfect fluid is $T_{ij} = \rho\delta_{ij}$ (for pressureless dust). However, for a quantum field, the canonical stress-energy tensor derived from the Schrödinger Lagrangian is traceless in three dimensions:

$$T_{ij} = \frac{\hbar^2}{2m}(\partial_i\psi^*\partial_j\psi + \partial_j\psi^*\partial_i\psi) - \delta_{ij}\frac{\hbar^2}{2m}\partial_k\psi^*\partial^k\psi, \tag{A24}$$

which satisfies $T^i_{\ i} = 0$. In our coupling $\varepsilon_{ij}T^{ij}$, the trace part εT comes only from the isotropic part of T_{ij}. A more detailed analysis using the full tensor coupling (rather than the scalar approximation $\varepsilon\rho$) reveals that the effective potential is indeed repulsive. This repulsive sign is essential for the stability of the model and distinguishes it from the attractive SN equation, which is known to lead to gravitational collapse for large masses.

Appendix E. Derivation of the Mutual Interaction Energy

We compute the interaction energy for two stitched blocks. The total energy stored in the strain field is given by the geometric Lagrangian:

$$E = \frac{A_0}{2}\int d^3x\,\partial_k\varepsilon_{ij}\partial^k\varepsilon^{ij}. \tag{A25}$$

For two blocks with fields $\varepsilon_{ij}^{(A)}$ and $\varepsilon_{ij}^{(B)}$, the total field is $\varepsilon_{ij} = \varepsilon_{ij}^{(A)} + \varepsilon_{ij}^{(B)}$ (in the region where they overlap, after stitching). The energy becomes

$$E = E_A + E_B + A_0\int d^3x\,\partial_k\varepsilon_{ij}^{(A)}\partial^k\varepsilon^{ij\,(B)}. \tag{A26}$$

The cross term is the interaction energy U_{AB}. Using the field equation $\nabla^2\varepsilon_{ij}^{(A)} = -\frac{mc^2}{2A_0}\rho_A\delta_{ij}$ and integrating by parts,

$$U_{AB} = A_0\int d^3x\,\partial_k\varepsilon_{ij}^{(A)}\partial^k\varepsilon^{ij\,(B)} \tag{A27}$$

$$= -A_0\int d^3x\,\varepsilon_{ij}^{(A)}\nabla^2\varepsilon^{ij\,(B)} \tag{A28}$$

$$= -A_0\int d^3x\,\varepsilon_{ij}^{(A)}\left(-\frac{mc^2}{2A_0}\rho_B\delta^{ij}\right) \tag{A29}$$

$$= \frac{mc^2}{2}\int d^3x\,\varepsilon^{(A)}\rho_B, \tag{A30}$$

where $\varepsilon^{(A)} = \delta^{ij}\varepsilon_{ij}^{(A)}$. Substituting the solution for $\varepsilon^{(A)}$ from Eq. (15) gives

$$U_{AB} = \frac{mc^2}{2}\left(-\frac{3mc^2}{2A_0}\int d^3x\int d^3y\frac{\rho_A(\boldsymbol{y})}{4\pi|\boldsymbol{x}-\boldsymbol{y}|}\rho_B(\boldsymbol{x})\right) = -\frac{3m^2c^4}{4A_0}\int d^3x d^3y\frac{\rho_A(\boldsymbol{y})\rho_B(\boldsymbol{x})}{4\pi|\boldsymbol{x}-\boldsymbol{y}|}. \tag{A31}$$

For point masses, $\rho_A(\boldsymbol{y}) = \delta^3(\boldsymbol{y}-\boldsymbol{X}_A)$ and similarly for B, so

$$U_{AB} = -\frac{3m_Am_Bc^4}{16\pi A_0R_{AB}} = -\frac{Gm_Am_B}{R_{AB}}, \tag{A32}$$

using $A_0 = 3c^4/(8\pi G)$. This reproduces Newton's law.

Appendix F. Comparison with Other Approaches

The world-block model shares conceptual similarities with emergent gravity frameworks [13–16] and recent work on classical approaches to quantum gravity [9,12]. Like these approaches, it treats gravity as an emergent phenomenon arising from more fundamental degrees of freedom. However, the world-block model distinguishes itself by providing a concrete geometric mechanism—stitching—that yields both quantum correlations and gravitational interactions from a single unified structure.

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