Sector-Resolved Measurement in a Scalar Refractive Gravity Framework: Unique Geometry, Pointer Fixing, and a Laboratory Discriminator

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We show that in a scalar refractive gravity framework (a "ψ-field" replacing curved spacetime), superposed mass distributions source *one* geometry, resolving the Penrose paradox of multiple spacetimes. Quantum evolution remains unitary under a self-adjoint Hamiltonian in that geometry. Because cavity photons and atomic transitions *couple unequally* to ψ (cavities track $c_1 = c\,e^{-\psi}$; atomic transitions either cancel leading ψ contributions or acquire a uniform fractional shift), meter states acquire ψ-dependent phases while the system does not (or does so differently), fixing the pointer basis and driving decoherence by environment coupling. We emphasize: *we do not derive outcome selection or the Born rule.* The concrete corollary is a laboratory test:

$$\frac{\Delta R}{R} = \xi\,\frac{\Delta\Phi}{c^2}, \qquad \xi \equiv \alpha_{\rm ph} - \alpha_{\rm at},$$

where $\alpha_{\rm ph}$ and $\alpha_{\rm at}$ parameterize photon and atomic ψ-response at leading order. General Relativity (GR) implies $\xi = 0$ (sector equality); any ψ-framework with sector asymmetry implies $\xi \neq 0$. On Earth this lever arm is 1.1×10^{-14} per 100 m — within reach of modern metrology.

NOTATION

We use $\delta\psi$ for infinitesimal/local changes (e.g. perturbation theory at a single location) and $\Delta\psi$ for finite differences between two altitudes. The gravitational potential difference satisfies $\Delta\psi = 2\,\Delta\Phi/c^2$.

INTRODUCTION

The quantum measurement problem has resisted a fully satisfactory resolution. Standard approaches (Copenhagen, many-worlds, de Broglie–Bohm) either invoke collapse, branches, or nonlocal hidden variables. Penrose sharpened this by pointing out that a quantum superposition of mass distributions should gravitationally source multiple geometries, which is inconsistent with a single wavefunction evolving unitarily [1, 2].

In a scalar refractive gravity approach, one posits a universal refractive index $n = e^{\psi(x)}$ such that the one-way speed of light is $c_1(x) = c\,e^{-\psi(x)}$. Matter accelerations follow $\mathbf{a} = \frac{c^2}{2}\nabla\psi$. The field obeys a nonlinear sourcing equation,

$$\nabla\cdot\Big[\mu\big(|\nabla\psi|/a_\star\big)\,\nabla\psi\Big] = -\frac{8\pi G}{c^2}\,(\rho-\bar\rho), \tag{1}$$

with a monotone crossover function μ. Under standard conditions for quasilinear elliptic PDEs, this has a unique solution for a given source. The key claim becomes: *any superposition sources exactly one* ψ.

We develop the following chain:
(1) Superpositions $\to$ one ψ geometry.
(2) Quantum evolution in that ψ background is unitary.
(3) Cavities (photons) and atoms can respond differently to ψ.

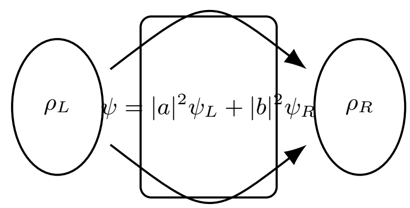

FIG. 1. Superposed densities source a single refractive field ψ; this mirrors how quantum expectation values source classical fields, e.g. $\langle j^\mu\rangle$ sourcing electromagnetism in semiclassical QED.

(4) This sectoral asymmetry pins the pointer basis; under generic environment coupling, the system decoheres in that basis.
(5) The falsifiable corollary: $\Delta R/R = \xi\,\Delta\Phi/c^2$ with $\xi = \alpha_{\rm ph} - \alpha_{\rm at}$.
(6) We do *not* derive the Born rule or single-outcome selection — that remains interpretational.

ONE ψ FOR SUPERPOSITIONS

Let $\hat\rho(x)$ be the mass density operator in the quantum state $|\Psi\rangle$. Define the effective classical source

$$\rho_{\rm eff}(x) = \langle\Psi|\hat\rho(x)|\Psi\rangle.$$

If $|\Psi\rangle = a|L\rangle + b|R\rangle$, then $\rho_{\rm eff} \approx |a|^2\rho_L + |b|^2\rho_R$. Inserting this into Eq. (1) yields a unique ψ (given monotonic μ), with no geometric branching.

Thus the Penrose objection (superpositions $\Rightarrow$ multiple geometries) is neutralized: only one ψ ever exists, determined by the expectation density.

QUANTUM EVOLUTION IN A ψ BACKGROUND

The single-particle Hamiltonian is

$$\hat{H} = -\frac{\hbar^2}{2m}\,\nabla\cdot\left(e^{-\psi}\nabla\right) + m\Phi, \qquad \Phi = -\frac{c^2}{2}\psi, \qquad (2)$$

which is self-adjoint with respect to the natural inner product; evolution $i\hbar\partial_t|\Psi\rangle = \hat{H}|\Psi\rangle$ is unitary with a conserved probability current.

Atomic ψ-response: constant vs gradient effects

Tiny gradient effects. On Earth, $\nabla\psi = 2g/c^2 \approx 2.2\times 10^{-16}\,\mathrm{m}^{-1}$. Over an atomic size $a_0 \sim 5\times 10^{-11}\,\mathrm{m}$, the variation $\delta\psi \lesssim 10^{-26}$. Perturbations from spatial variation (both in the kinetic operator and in $m\Phi(\mathbf{x})$) therefore produce *level-dependent* fractional shifts $\lesssim 10^{-26}$, utterly negligible compared to the $\sim 10^{-14}$ altitude lever arm of our experiment.

Constant ψ_0: uniform fractional scaling (hydrogenic example). Write $\psi(\mathbf{x}) = \psi_0 + \delta\psi(\mathbf{x})$ with $\delta\psi$ neglected. Then

$$\hat{H} \approx e^{-\psi_0}\left(-\frac{\hbar^2}{2m}\nabla^2\right) + V_{\mathrm{EM}} + m\Phi_0, \quad \Phi_0 = -\frac{c^2}{2}\psi_0.$$

The common shift $m\Phi_0$ cancels in all transition frequencies. Treat the kinetic prefactor as a small perturbation $\delta\hat{H} = -\psi_0\hat{T}$ with $\hat{T} = -\frac{\hbar^2}{2m}\nabla^2$. For Coulomb binding, the virial theorem gives $\langle T\rangle_n = -E_n$ (with $E_n < 0$). First-order perturbation theory yields

$$\delta E_n = \langle n|\delta\hat{H}|n\rangle = -\psi_0\langle T\rangle_n = \psi_0 E_n,$$

so each bound energy acquires the *same fractional shift* $\delta E_n/E_n = \psi_0$. For transitions,

$$\frac{\delta\omega_{ab}}{\omega_{ab}} \equiv \frac{\delta(E_a - E_b)}{E_a - E_b} = \frac{\psi_0(E_a - E_b)}{E_a - E_b} = \psi_0,$$

confirming uniformity for transition frequencies at leading order. We denote this atomic leading-order coefficient by $\alpha_{\mathrm{at}} = +1$ in this minimal, kinetic-only model.[1]

[1] More general atoms (non-Coulombic potentials, relativistic and QED corrections) preserve the conclusion that a constant multiplicative change of the kinetic operator induces a uniform first-order fractional shift across transitions, modulo small state-dependent corrections; the uniformity follows from virial-type relations for homogeneous potentials. If electromagnetic parameters co-vary with ψ in matter such that V_{EM} picks up compensating factors, the net α_{at} can be reduced or nulled ($\alpha_{\mathrm{at}} \simeq 0$); the experiment measures $\xi = \alpha_{\mathrm{ph}} - \alpha_{\mathrm{at}}$.

Cavity photons and ψ

For a rigid cavity of length L and longitudinal mode index $q \in \mathbb{N}$, the resonance is

$$f_{\mathrm{cav}} = \frac{q\,c_1}{2L}, \qquad c_1 = c\,e^{-\psi}.$$

Thus

$$\frac{\delta f_{\mathrm{cav}}}{f_{\mathrm{cav}}} = -\,\delta\psi \quad\Rightarrow\quad \alpha_{\mathrm{ph}} = -1,$$

assuming L is fixed by rigid body mechanics at the relevant precision (elastic/thermal effects bounded as systematics).

Sector coefficients and what the experiment measures

Summarizing the leading-order fractional responses for a small local change $\delta\psi$:

$$\frac{\delta f_{\mathrm{cav}}}{f_{\mathrm{cav}}} = \alpha_{\mathrm{ph}}\,\delta\psi, \quad \frac{\delta f_{\mathrm{at}}}{f_{\mathrm{at}}} = \alpha_{\mathrm{at}}\,\delta\psi.$$

In the kinetic-only hydrogenic estimate above, $\alpha_{\mathrm{at}} = +1$. If electromagnetic material parameters co-vary with ψ within solids and atoms such that internal energies receive compensating factors, α_{at} can be suppressed ($\alpha_{\mathrm{at}} \simeq 0$ in an ideal nondispersive cancellation). Our proposed observable is the *difference*

$$\xi \equiv \alpha_{\mathrm{ph}} - \alpha_{\mathrm{at}}.$$

GR enforces sector equality and hence $\xi = 0$. Any inequivalence gives $\xi \neq 0$. The experiment measures ξ directly.

POINTER BASIS: OPERATIONAL (METER-CHOSEN)

Let system S (atom) and meter M (cavity photons) interact and then couple to the environment E. The total Hamiltonian reads

$$\hat{H}_{\mathrm{tot}} = \hat{H}_S[\psi] + \hat{H}_M[\psi] + \hat{H}_{SM} + \hat{H}_{ME}.$$

Because $\hat{H}_M$ imprints ψ-dependent phases on meter states with coefficient α_{ph} while $\hat{H}_S$ imprints with (possibly different) α_{at}, the *meter* determines the pointer basis in which decoherence occurs. If one instead engineered an atomic (matter-sector) meter, the pointer basis would follow the corresponding atomic eigenstates. This is fully standard in environment-induced superselection: the apparatus/environment coupling selects the basis.

INFLUENCE FUNCTIONAL PROOF OF DECOHERENCE

We give the reduced density matrix evolution explicitly.

Setup. Initial state

$$|\Psi_0\rangle = \sum_i c_i\,|s_i\rangle \otimes |m_0\rangle \otimes |E_0\rangle.$$

Under unitary evolution $U(t)$ generated by $\hat{H}_{\rm tot}$, the state at time t can be written (in a standard pre-measurement model) as

$$|\Psi(t)\rangle = \sum_i c_i\,|s_i\rangle \otimes |m_i(t)\rangle \otimes |E_i(t)\rangle,$$

where $|m_i(t)\rangle = e^{-i\hat{H}_M^{(i)}t/\hbar}|m_0\rangle$ and $|E_i(t)\rangle$ incorporate the M–E interactions conditioned on branch i.

Reduced state and influence functional. Tracing out ME,

$$\rho_S^{ij}(t) = c_i c_j^*\,\mathcal{F}_{ij}(t), \qquad \mathcal{F}_{ij}(t) \equiv \langle m_j(t)|m_i(t)\rangle\,\langle E_j(t)|E_i(t)\rangle.$$

Because $\hat{H}_M$ depends on ψ with coefficient $\alpha_{\rm ph}$ while $\hat{H}_S$ depends with $\alpha_{\rm at}$, distinct branches $i \neq j$ accumulate different meter phases

$$\langle m_j(t)|m_i(t)\rangle \sim \exp\Big\{\frac{i}{\hbar}\int_0^t dt'\,\Delta H_M^{(ij)}[\psi(t')]\Big\},$$

with $\Delta H_M^{(ij)}$ proportional to $(\alpha_{\rm ph} - \alpha_{\rm at})\,\delta\psi$ through the S–M coupling. Coupling to E induces damping of off-diagonal terms; in the Born–Markov limit one obtains

$$|\langle E_j(t)|E_i(t)\rangle| \approx \exp\big(-\Gamma t\big),$$

for some decoherence rate Γ set by M–E couplings. Hence

$$|\mathcal{F}_{ij}(t)| \to 0 \quad (i \neq j),$$

and

$$\rho_S(t) \approx \sum_i |c_i|^2 |s_i\rangle\langle s_i|.$$

We stress: this *does not* derive selection of one outcome or the Born rule; it shows suppression of interference in a basis fixed by sector response and apparatus coupling.

EXPERIMENTAL COROLLARY: ALTITUDE SLOPE

At a single location, a small local change $\delta\psi$ gives

$$\frac{\delta R}{R} \equiv \frac{\delta(f_{\rm cav}/f_{\rm at})}{(f_{\rm cav}/f_{\rm at})} = (\alpha_{\rm ph} - \alpha_{\rm at})\,\delta\psi \equiv \xi\,\delta\psi.$$

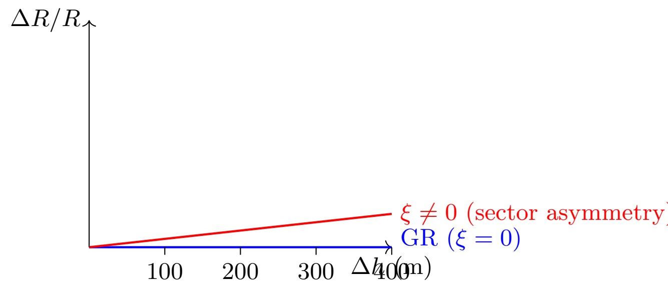

FIG. 2. Predicted cavity–atom slope: null (GR, $\xi = 0$) vs non-null ($\xi \neq 0$). Linear-gradient model is valid over $\lesssim 400$ m; curvature corrections are $< 10^{-18}$ and negligible at present precision.

Between two altitudes separated by Δh on Earth,

$$\Delta\psi = \frac{2\,\Delta\Phi}{c^2} \approx \frac{2\,g\Delta h}{c^2},$$

so the finite change is

$$\frac{\Delta R}{R} = \xi\,\frac{\Delta\Phi}{c^2}.$$

With $g\Delta h/c^2 \approx 1.1 \times 10^{-14}$ per 100 m, a nonzero ξ produces a clean, linear slope; $\xi = 0$ gives a strict null. Modern cavities (stability 10^{-16}–10^{-17}) and optical clocks ($< 10^{-18}$) make this test feasible.

RELATION TO EXISTING EXPERIMENTS AND WHY THIS IS UNTESTED

High-precision redshift tests comparing *atom vs atom* clocks have reached fractional 10^{-17} over 33–40 cm [3]. Transportable optical lattice clocks have compared sites separated by $\sim$ 100–450 m [4]. Ultra-stable cavities (room-temperature and cryogenic) reach 10^{-16}–10^{-17} linewidths and underpin state-of-the-art optical clocks [5, 6]. Searches for ultralight dark matter also compare cavity and atomic references, but probe *temporal* modulations, not an *altitude* slope [7].

To our knowledge, a *stationary, two-altitude, sector-resolved* measurement of $f_{\rm cav}/f_{\rm at}$ reporting a geometry-locked slope at the 10^{-14}/100 m level has not been published. This likely reflects practical priorities (atomic-to-atomic comparisons for timekeeping) rather than impossibility: the required components are standard. A dedicated protocol with dispersion bounds, orientation flips, and hardware swaps would decisively determine ξ.

CONCLUSION

This framework eliminates the Penrose paradox by enforcing one geometry, shows how the pointer basis is fixed by sector response (operationally, by the meter), and reduces a conceptual tension to a falsifiable, binary discriminator. We make no claim to derive outcome selection. The experiment measures $\xi = \alpha_{\mathrm{ph}} - \alpha_{\mathrm{at}}$ via a height-dependent slope of $f_{\mathrm{cav}}/f_{\mathrm{at}}$ at $\sim 10^{-14}/100\,\mathrm{m}$. *Independent of whether* $\alpha_{\mathrm{at}} \approx 0$ *(material co-variance) or* $\alpha_{\mathrm{at}} \approx +1$ *(kinetic-only scaling), the key discriminator is* ξ*: any* $\xi \neq 0$ *signals physics beyond GR's sector equality.*

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