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Scalar Selection: A Research Program for Emergent Timing Geometry - Framework, Microscopic Route, Closure Tests, and Experimental Design

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A Test Protocol for Scalar Timing Closure and Dimensional Selection

Evidence · Scalar source/window residual audit

Scalar Selection: A Research Program for Emergent Timing Geometry

Framework, Microscopic Route, Closure Tests, and Experimental Design

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Abstract

We formulate an integrated research program for systems in which a scalar response field may be the first stable geometric observable to survive coarse graining. The framework begins from an effective weighted graph extracted from a structured medium or substrate and posits a screened weighted-Laplacian closure for a scalar load field, $(\kappa L_w + \mu^2 I)\Lambda = A\rho$. Local clock rates couple to this load through a weak timing law, $\omega_{\text{eff}} = \omega/(1 + \alpha\Lambda)$, making timing observables the primary experimental probes. The same operator that governs scalar response also defines an effective spectral dimension through return-probability scaling, yielding a central closure test: these independent dimension estimators must agree within the same scaling window in which the timing law fits best. We derive the microscopic route from coupler physics in reconfigurable superconducting networks, classify the internal-to-external coupling kernels that determine whether the scalar sector is externally accessible, develop a concrete experimental program with six discriminants for timing-first detection, work through a 20-node ring-versus-star example, and define a numerical workflow with explicit pass/fail criteria. The framework does not assume full emergent gravitation, tensor completion, or universal externalization. Its claim is narrower: a scalar timing sector may arise as a selected observable layer of structured systems, and its validity can be tested by operator closure, dimensional coincidence, medium realizability, and timing-first experimental discriminants. The program is intentionally designed to fail cleanly.

Program spine.

$$H_{\text{micro}} \;\to\; W \;\to\; L_w \;\to\; d_{\text{eff}} \;\to\; G_{d_{\text{eff}}}(r) \;\to\; \Lambda(r) \;\to\; \omega_{\text{eff}}$$

This chain is treated as a hierarchy of effective levels rather than a fully derived identity. The closure problem lives at the effective and observable levels.

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1 Introduction

Physical theories are often developed in the opposite order from how observability actually works. One begins with a deep ontology, then asks what a measurement might see. But many systems do not present their full microscopic state to experiment. They present a reduced, stabilized layer: a smaller algebra of observables that survives coarse graining, noise, finite resolution, and dynamical selection. The scientific question addressed here is whether a scalar timing sector can be such a survivor.

The proposal is deliberately narrow. We do not assume that a full metric theory has emerged. We do not assume that every structured medium supports an externally measurable field. We do not assume that a scalar sector, if found, is already gravity. Instead, we ask whether there exists a robust effective regime in which a single graph-based operator simultaneously controls scalar response, effective dimension, and timing observables. This is the minimal closure problem.

The thesis is therefore modest: a structured substrate may admit a reduced observable sector in which a scalar load field is the first stable geometric quantity to survive coarse graining, and in which local timing observables provide the primary experimental access to that sector. If this thesis is false, the failure should be sharp: no common scaling window, no operator closure, no stable timing law, no realizable medium, or no external coupling. If it is true, scalar timing geometry becomes a legitimate scientific object in its own right.

The guiding principle throughout is not *what exists*, but *what survives*. This pattern—local lawful dynamics plus constraint plus selection yielding a stable visible form—appears across many domains of physics. In strain-engineered bilayer nickelates, picometer-scale octahedral distortions reorganize the low-energy sector and correlate with superconductivity [17, 18]. In photonic crystals and directional antennas, local periodic structure selects which propagation modes survive into the far field. In compact Bonnet pairs, the same local metric and mean-curvature data fail to determine a unique global immersion [19]. The present proposal asks whether fundamental physics may obey the same logic: a world is not simply "what is there" but what holds together.

2 Scalar Selection as a Coarse-Graining Hypothesis

By scalar selection we mean neither metaphysical preference nor universal scalar ontology. We mean something operational: among the many microscopic degrees of freedom of a structured system, a scalar response sector may be the first one to survive coarse graining as a stable, reproducible, weakly local observable geometry. This definition treats survival under coarse graining as the criterion of relevance. A variable matters not because it exists microscopically, but because it persists into the observable layer.

This framing is explicitly level-aware. An internal scalar load on graph vertices is not yet an external field at a sensor. A fitted timing response is not yet a microscopic derivation. A successful closure test is not yet a tensor theory. These distinctions are not cosmetic. They are what keep the program from inflating suggestive effective structure into unsupported ontology.

The framework is medium-agnostic by design. Reconfigurable superconducting networks provide one plausible route because they already realize programmable weighted graphs and timing-sensitive internal observables, but the scalar-selection hypothesis is not logically tied to that medium class alone.

To state the projection sharply: let ρ_{micro} denote the promoted microscopic state. The scalar program retains not the full operator algebra of the promoted graph but a smaller observable

algebra generated by quantities such as

$$\mathcal{A}_{\text{scalar}} = \text{alg}\big\{\langle n_{ij}\rangle,\ \Lambda_i,\ P_{\text{return}}(t),\ \omega_{\text{eff}}(i)\big\}. \tag{1}$$

The corresponding coarse-graining channel may be written schematically as

$$\mathcal{E} : \rho_{\text{micro}} \ \mapsto\ \big\{\langle n_{ij}\rangle,\ \Lambda_i,\ P_{\text{return}}(t),\ \omega_{\text{eff}}(i)\big\}. \tag{2}$$

What is projected out includes microscopic bond-phase information, higher connected correlations, nonlocal entanglement structure not visible in Λ, and any would-be tensorial sector not represented in the retained scalar observables.

3 Effective Graph Description

Let a structured system, after suitable extraction or coarse graining, be represented by a weighted graph $G = (V, E, w)$, with nonnegative symmetric weights w_{ij}. The weight matrix $W = (w_{ij})$ encodes effective couplings. The degree matrix is $D_{ii} = \sum_j w_{ij}$, and the weighted Laplacian is

$$L_w = D - W. \tag{3}$$

For any function $\varphi : V \to \mathbb{R}$,

$$(L_w\varphi)(i) = \sum_j w_{ij}\big[\varphi(i) - \varphi(j)\big]. \tag{4}$$

This graph is not assumed to be fundamental. It is the retained effective object through which scalar response, diffusion, and timing observables will be described. Its microscopic origin may vary. In different realizations the weights may be extracted from programmable couplings, bond occupations, frustration indicators, dressed interactions, or other medium-specific maps. The closure program does not require the same microscopic route in all cases. It requires that a promoted or effective weighted graph be extractable at all.

The discrete Green-function and heat-kernel literature provides the relevant mathematical backdrop [3, 1, 2, 4]. The graph Laplacian supports both diffusion operators and Green responses; these connect geometry, return probabilities, and long-distance response structure. The program proposed here is to use that operator commonality not merely as mathematics, but as a scientific discriminator.

4 Leading Scalar Closure

The leading scalar response is postulated to satisfy

$$(\kappa L_w + \mu^2 I)\Lambda = A\rho, \tag{5}$$

where Λ is the retained scalar load, ρ is an effective source, $\kappa > 0$ is a graph-transport or stiffness coefficient, $\mu \geq 0$ is a screening scale, and A sets source amplitude. When time-resolved behavior matters, the minimal dynamical completion is

$$\partial_t\Lambda + \Gamma(\kappa L_w + \mu^2 I)\Lambda = \Gamma A\rho(t). \tag{6}$$

This closure is not justified by familiarity alone. It is selected as the lowest-order closure satisfying five weak-load requirements:

(i) linearity in the source for separated weak perturbations,

(ii) locality on the effective graph,

(iii) invariance under graph relabelings and symmetries,

(iv) positivity or ellipticity of the response,

(v) minimal operator order.

Equivalently, the static closure is the Euler–Lagrange equation of the quadratic roughness-plus-screening functional

$$F[\Lambda] = \frac{\kappa}{2}\langle \Lambda, L_w \Lambda \rangle + \frac{\mu^2}{2}\|\Lambda\|^2 - A\langle \rho, \Lambda \rangle. \tag{7}$$

The first term penalizes roughness across strongly coupled edges, the second penalizes unsustained bulk load, and the third injects source structure.

Nonlinear or higher-order closures,

$$(\kappa L_w + \mu^2 I)\Lambda + \beta\Lambda^2 = A\rho, \qquad (\kappa_1 L_w + \kappa_2 L_w^2 + \mu^2 I)\Lambda = A\rho, \tag{8}$$

are not excluded in principle. They belong to the next order of the effective theory. The present program studies the leading weak-load closure and asks whether that leading closure already closes the observable scalar sector.

5 Effective Dimension from the Same Operator

The same weighted Laplacian defines a diffusion semigroup $K(t) = e^{-tL_w}$ and mean return probability

$$P_{\text{return}}(t) = \frac{1}{|V|}\operatorname{Tr} K(t). \tag{9}$$

When a scaling regime exists, the diffusion-based effective dimension is

$$d_{\text{eff}}^{(\text{diff})}(t) = -2\,\frac{d\log P_{\text{return}}(t)}{d\log t}. \tag{10}$$

This definition is intrinsic to the promoted graph and requires no preassigned embedding dimension [1, 2].

Independently, for a chosen source or hotspot, define graph shells S_r and shell-averaged scalar load

$$\Lambda_{\text{shell}}(r) = \frac{1}{|S_r|}\sum_{i\in S_r}\Lambda_i. \tag{11}$$

In a Gaussian scaling regime, the asymptotic profile is expected to behave as

$$\Lambda_{\text{shell}}(r) \sim \begin{cases} r^{2-d_{\text{eff}}}, & d_{\text{eff}} \neq 2, \\ \log r, & d_{\text{eff}} = 2. \end{cases} \tag{12}$$

Thus one can define the shell-based estimator

$$d_{\text{eff}}^{(\Lambda)}(r) = 2 - \frac{d\log|\Lambda_{\text{shell}}(r)|}{d\log r}. \tag{13}$$

The central mathematical point is that scalar response and effective dimension are not two separate interpretations layered onto the same graph. They are two observables derived from the same operator. That operator commonality is what makes the framework testable.

5.1 The Gaussian window is a hypothesis to be diagnosed

For a dynamically generated promoted graph, Gaussian asymptotics are not automatic. Recent work on heat kernels on weighted and isoradial graphs makes clear that discrete systems can exhibit Gaussian-like and non-Gaussian regimes depending on scale, geometry, and weighting structure [4]. A practical Gaussian window is supported when three conditions hold over overlapping scales:

(i) the return probability exhibits an approximately constant slope, $P_{\mathrm{return}}(t) \sim t^{-d_{\mathrm{eff}}/2}$;

(ii) the shell profile exhibits a matching power-law or logarithmic law;

(iii) the source-response relation remains approximately additive for weak separated sources.

Expected failure modes include strong anisotropy of w_{ij}, heavy-tailed disorder in the weight distribution, bottlenecks, tree-like sparsity, small-world shortcuts, and finite-size saturation. In those cases $d_{\mathrm{eff}}(t)$ may drift strongly with scale and the Green profile may become stretched, crossover-like, or non-power-law. This is not a nuisance to be hidden. It is part of the theory: if the Gaussian regime fails, then the scalar law should not be expected to mimic the familiar weak-field branch.

6 The Central Closure Criterion

The decisive test is not whether either the timing law or a dimension estimate works in isolation. It is whether they cohere in the same scaling regime:

$$\boxed{d_{\mathrm{eff}}^{(\mathrm{diff})} \approx d_{\mathrm{eff}}^{(\Lambda)} \quad \text{in the same window where Eq. (15) fits best.}} \tag{14}$$

A convincing closure window should satisfy all of the following:

(i) the diffusion-based dimension is approximately constant over a nontrivial interval, ideally approaching a decade in diffusion time or radial scale;

(ii) the shell-based dimension agrees with it within uncertainty;

(iii) the timing-law residual is locally minimized in that same interval;

(iv) the result is reasonably stable under changes in graph size, source placement, and extraction threshold;

(v) the inferred value drifts more slowly with increasing N rather than more quickly.

A transient crossing through some desired value without plateau behavior, window overlap, or finite-size stability is merely suggestive. This operator-level coincidence is the scientific heart of the program. Everything else is interpretation layered on top of it.

7 Timing as the First Observable Geometry

The operational observable map is

$$\omega_{\mathrm{eff}} = \frac{\omega}{1+\alpha\Lambda}, \qquad \frac{\delta\omega}{\omega} \approx -\alpha\Lambda \quad \text{for } |\alpha\Lambda| \ll 1. \tag{15}$$

The claim is not that every clock is fundamentally scalar. The claim is narrower: if a scalar load sector survives coarse graining, then local timing observables provide a natural first measurement channel. Timing is often more directly accessible, more differential, and more precise than

force-level channels, especially in weak regimes. This is why the program emphasizes timing-before-force as an experimental grammar rather than a metaphysical slogan.

Equation (15) should be treated as an effective constitutive relation. Its job is to connect a retained scalar observable to a measurable frequency shift. By itself it neither implies metric completion nor settles whether the scalar sector is internal only or externally accessible.

8 The Special Role of Three and the Viability Window

8.1 The 1/r branch

Inserting the Green-law profile (12) into the timing law (15) gives, for a point source,

$$\frac{\delta\omega(r)}{\omega} \approx -\alpha A\, G_{d_{\text{eff}}}(r). \tag{16}$$

For the value $d_{\text{eff}} = 3$, the Green kernel becomes $G_3(r) \propto 1/r$, so

$$\Lambda(r) \sim \frac{A}{r}, \qquad \frac{\delta\omega}{\omega} \sim -\frac{\alpha A}{r}. \tag{17}$$

This is the correct envelope for weak-field gravitational redshift, $d\tau/dt \approx 1 - GM/(rc^2)$, with the matching condition $\alpha A \sim GM/c^2$.

Proposition 1 (Scalar dimensional closure)**.** *If the promoted graph geometry admits a Gaussian scaling regime with effective spectral dimension d_{eff}, and if the scalar load obeys the Green-response closure* (5)*, then the weak-field scalar redshift law has radial envelope $r^{2-d_{\text{eff}}}$, with the Newtonian $1/r$ branch occurring if and only if $d_{\text{eff}} = 3$.*

8.2 Dimensional survivability

Not all effective dimensions are equally able to host stable observable worlds. Two classical constraints apply.

First, for a central attractive potential $V(r) = -k/r^n$ with $n = d_{\text{eff}} - 2$, stable circular orbits require $n < 2$, hence $d_{\text{eff}} < 4$. Above this threshold the effective potential no longer supports a stable bound minimum.

Second, graph diffusion changes qualitatively at spectral dimension 2. Below that threshold random walks are recurrent; above it they are transient. In recurrence-dominated geometries, the long-range decoupling needed for persistent large-scale structure and independent records is compromised. This suggests $d_{\text{eff}} > 2$.

Proposition 2 (Dimensional survivability window)**.** *If an observable sector must support both persistent record structure and stable long-range binding, then the effective dimension must lie in the interval $2 < d_{\text{eff}} < 4$. The branch that simultaneously lies inside this window and reproduces the familiar $1/r$ weak-field envelope is $d_{\text{eff}} \approx 3$.*

8.3 Proper conditioning

What is justified is the following conditional statement: *if* the promoted graph supports a Gaussian scaling window, and *if* the leading scalar closure holds there, then the scalar load profile inherits the Green-law exponent determined by the same effective dimension, and the $1/r$ branch occurs at $d_{\text{eff}} \approx 3$. The coincidence makes three a privileged target value for closure tests. What is *not* yet justified is a strong claim that cosmic three-dimensionality is derived from this mechanism alone. The viability window $2 < d_{\text{eff}} < 4$ is a consistency condition, not a selection mechanism; establishing whether $d_{\text{eff}} \approx 3$ is dynamically selected within that window, or merely the branch we happen to inhabit, requires an independent dynamical argument that this paper does not supply.

9 Internal Loads Versus External Observables

One of the most important distinctions in the program is that an internal scalar load Λ_i defined on graph vertices does not by itself imply an externally measurable scalar geometry. An external sensor at position x measures, at best,

$$\Lambda_{\rm ext}(x) = \sum_i C(x,i)\,\Lambda_i, \tag{18}$$

where $C(x,i)$ is an internal-to-external coupling kernel. The nature of this kernel must be specified, measured, or bounded. Internal closure and external accessibility are separate empirical questions. This distinction prevents the framework from smuggling in externalization claims that have not been earned.

9.1 Kernel classification

Five classes exhaust the main possibilities:

Near-field / evanescent kernel. The external response is dominated by short-range coupling,

$$C_{\rm ev}(x,i) \sim C_0\, e^{-d(x,i)/\ell_c}, \tag{19}$$

where $d(x,i)$ is physical distance and ℓ_c is a coupling depth. Observable effects are confined to small distances. This class predicts strong dependence on probe standoff and substrate thickness.

Substrate-mediated diffusive kernel. The scalar load couples into another medium degree of freedom (mechanical, thermal, dielectric, or phononic) which carries the signal outward:

$$(\eta\nabla^2 - m_s^2)\Phi_s(x) = B\sum_i \delta(x-x_i)\Lambda_i, \tag{20}$$

with measured response $\Lambda_{\rm ext}(x) = \Phi_s(x)$. This class predicts finite propagation delays and potentially broad relaxation tails.

Radiative / boundary-modulated kernel. The internal scalar load modulates a boundary condition or effective impedance seen by an electromagnetic or microwave mode:

$$\Lambda_{\rm ext}(x,\omega) = \sum_i C_{\rm rad}(x,i;\omega)\,\Lambda_i. \tag{21}$$

This class predicts resonant enhancement and strong sensitivity to cavity or resonator tuning.

Vacuum / effective Green-response kernel. The most ambitious possibility: the internal scalar load sources an effective external scalar field through a spatial Green kernel,

$$\Lambda_{\rm ext}(x) = \sum_i G_{\rm ext}(x,x_i)\,\Lambda_i, \qquad G_{\rm ext}(r) \sim r^{2-d_{\rm eff}^{\rm ext}}. \tag{22}$$

This is the strongest externalization claim and requires the clearest evidence.

Null kernel. A perfectly respectable outcome is $C(x,i) \approx 0$ outside the medium. In that case the scalar load is an internal medium observable only. This does not kill the program, but it limits what can be claimed experimentally.

9.2 How to distinguish kernel classes

A minimal external-coupling experiment should vary: (i) probe distance from the medium, (ii) substrate thickness and material, (iii) drive frequency and switching rate, (iv) graph topology at fixed mass, and (v) shielding and cavity boundary conditions. The goal is not to identify the kernel in one shot, but to eliminate classes. If the response vanishes rapidly with standoff and changes strongly with substrate, the evanescent or substrate-mediated classes dominate. If the response follows cavity tuning, a radiative kernel is implicated. If a clean power-law tail survives controls, the vacuum-like class becomes more plausible.

Kernel class	Distance law	Distinctive signature
Near-field / evanescent	Exponential / short-range	Strong suppression with standoff
Substrate-mediated	Medium-dependent	Time-delayed and broadened response
Radiative / boundary	Resonant / mode-dependent	Frequency-selective enhancement
Vacuum / Green-response	Power law or screened	Not reducible to substrate coupling
Null	None	Internal sensor sees effect; external sees nothing

Table 1: Observable signatures of the five kernel classes.

10 Microscopic Route: From Coupler Physics to Scalar Closure

A speculative theory begins to mature only when its effective equations cease to float above matter and become traceable to some real substrate. This section derives the scalar closure from a concrete medium class: superconducting arrays with tunable couplers [10, 11, 12].

10.1 Medium Hamiltonian

Consider a network of node modes coupled by tunable elements on graph edges. A minimal microscopic Hamiltonian is $H = H_{\text{nodes}} + H_{\text{coup}} + H_{\text{int}} + H_{\text{drive}} + H_{\text{diss}}$, with

$$H_{\text{nodes}} = \sum_i \Big[\omega_i a_i^\dagger a_i + \frac{K_i}{2} a_i^\dagger a_i^\dagger a_i a_i\Big], \tag{23}$$

$$H_{\text{coup}} = \sum_{\langle i,j\rangle} \Omega_{ij} b_{ij}^\dagger b_{ij}, \tag{24}$$

$$H_{\text{int}} = \sum_{\langle i,j\rangle} g_{ij}(t)(a_i + a_i^\dagger)(b_{ij} + b_{ij}^\dagger) + g_{ji}(t)(a_j + a_j^\dagger)(b_{ij} + b_{ij}^\dagger). \tag{25}$$

After the usual rotating-frame reduction, bias-point expansion, and elimination of strongly off-resonant sectors, the retained microscopic effective Hamiltonian takes the familiar form

$$H_{\text{eff,micro}} = \sum_i \tilde{\omega}_i n_i + \sum_{\langle i,j\rangle} J_{ij}(t)(a_i^\dagger a_j + a_j^\dagger a_i) + \sum_{\langle i,j\rangle} \chi_{ij} n_i n_j + \cdots \tag{26}$$

10.2 The scalar observable

The scalar quantity that plays the role of Λ_i is the local dressed-frequency load,

$$\Lambda_i \equiv \frac{\delta\omega_i^{\text{dress}}}{\omega_*}, \qquad \delta\omega_i^{\text{dress}} \equiv \tilde{\omega}_i - \omega_i^{(\text{ref})}, \tag{27}$$

normalized to a reference frequency ω_*. This choice is natural because it is scalar, directly tied to timing through phase accumulation, and the scalar quantity most directly matched to the timing law (15). It is known in superconducting systems that coupler bias, local occupation, and interaction dressing shift effective frequencies.

An immediate clarification: Eq. (27) defines an *internal* scalar load on graph vertices. By itself this does not imply an externally measurable field in the space surrounding the chip. The internal–external distinction of Section 9 applies in full.

10.3 From coupler graph to weighted Laplacian

The programmable coupling graph is encoded in the effective couplings from Eq. (26). The weighted graph is defined by

$$w_{ij} = f(J_{ij}, \chi_{ij}, \bar{n}_i, \bar{n}_j, \text{bias point}), \tag{28}$$

with the leading choice simply $w_{ij} \approx |J_{ij}|$. The weighted Laplacian is then $L_w = D - W$ as in Eq. (3). This graph is not a visual analogy. It is the physical coupling matrix of the medium.

10.4 Separation of scales and leading closure

The key step is to separate fast and slow variables. One partitions the microscopic variables into a slow retained sector s (the dressed-frequency loads) and a fast sector f (coupler-conditioned amplitudes, occupations, and bias-relaxation variables), linearizes about a stable operating point, and writes the coupled equations schematically as

$$\dot{s} = A_{ss}s + A_{sf}f + \eta_s, \tag{29}$$

$$\dot{f} = A_{ff}f + A_{fs}s + \eta_f, \tag{30}$$

with $\|A_{ff}\|$ setting a faster timescale than $\|A_{ss}\|$. The leading elimination is the Markovian adiabatic-elimination step

$$f(t) \approx -A_{ff}^{-1}A_{fs}\, s(t), \tag{31}$$

which is the zeroth-order truncation of a more general Nakajima–Zwanzig or memory-kernel treatment. Substituting back gives

$$\dot{s} \approx \big(A_{ss} - A_{sf}A_{ff}^{-1}A_{fs}\big)s + \tilde{\eta}_s, \tag{32}$$

so the effective slow generator is the Schur complement of the fast block.

The dressed shift can be expanded in the fast coupler-conditioned variables. Linearizing around the reference state and retaining only the first variation, if neighboring nodes are coupled through shared coupler-conditioned variables, the elimination of the fast variables generates a nearest-neighbor redistribution term proportional to differences of the retained scalar load:

$$\dot{\Lambda}_i \approx A\rho_i + \kappa \sum_j w_{ij}(\Lambda_j - \Lambda_i) - \mu^2\Lambda_i, \tag{33}$$

which rearranges into

$$\partial_t\Lambda + \Gamma(\kappa L_w + \mu^2 I)\Lambda = \Gamma A\rho(t). \tag{34}$$

This is the scalar closure (6), now derived from a specific medium class rather than postulated.

The parameters have clear meaning: κ is the graph-transport or stiffness coefficient of scalar-load redistribution; μ is a screening scale arising from leakage, damping, finite coherence depth, or environmental relaxation; and $A\rho_i$ is the effective source generated by graph-state switching, local bias imbalance, or other departures from the reference configuration. Memory corrections enter at the next order when the time dependence of s inside the convolution integral is retained rather than frozen. The leading closure is expected to break when any of the following become important:

$$(\kappa L_w + \mu^2 I)\Lambda = A\rho + \beta\Lambda^2 + \eta L_w^2\Lambda + \int_0^t M(t-s)\Lambda(s)\, ds + \cdots \tag{35}$$

10.5 Two-node elimination example

To make the elimination step explicit, consider two retained node loads $s = (\Lambda_1, \Lambda_2)^T$ and one fast coupler variable $f = X$. Linearizing near an operating point gives

$$\dot{\Lambda}_1 = -a\Lambda_1 + bX + A\rho_1, \tag{36}$$

$$\dot{\Lambda}_2 = -a\Lambda_2 + bX + A\rho_2, \tag{37}$$

$$\dot{X} = -\Omega X + c(\Lambda_1 + \Lambda_2) + d(\Lambda_2 - \Lambda_1), \tag{38}$$

with $\Omega \gg a$. The adiabatic elimination sets $X \approx [c(\Lambda_1 + \Lambda_2) + d(\Lambda_2 - \Lambda_1)]/\Omega$. Substituting back and retaining the antisymmetric component gives

$$\dot{\Lambda}_1 \approx -\Big(a + \frac{bd}{\Omega}\Big)\Lambda_1 + \frac{bd}{\Omega}\Lambda_2 + A\rho_1 + \text{symmetric terms}, \tag{39}$$

$$\dot{\Lambda}_2 \approx -\Big(a + \frac{bd}{\Omega}\Big)\Lambda_2 + \frac{bd}{\Omega}\Lambda_1 + A\rho_2 + \text{symmetric terms}. \tag{40}$$

In vector form, absorbing symmetric renormalizations into μ^2, this becomes

$$\partial_t \Lambda + \Gamma(\kappa L + \mu^2 I)\Lambda = \Gamma A \rho, \tag{41}$$

with L the two-node graph Laplacian, $\kappa \propto bd/\Omega$, and $\mu^2 \propto a$. If one does not freeze X instantaneously, the elimination produces a retarded convolution kernel—the origin of the memory correction discussed above.

11 Worked Example: 20-Node Ring Versus Star

A specific graph pair clarifies the formalism and shows how the program generates concrete predictions. Consider a 20-node array reconfigured between two equal-mass graph states: a uniform ring C_{20} and a uniform star S_{20}, both with edge weight w.

11.1 Ring spectrum

The Laplacian eigenvalues of the ring are

$$\lambda_k^{\text{ring}} = 2w\Big(1 - \cos\frac{2\pi k}{20}\Big), \quad k = 0, 1, \ldots, 19. \tag{42}$$

The smallest nonzero eigenvalue is $\lambda_1^{\text{ring}} = 2w(1 - \cos(\pi/10)) \approx 0.0979\, w$.

11.2 Star spectrum

The star with one hub and 19 leaves has spectrum $\{0,\ w^{(18)},\ 20w\}$, so the slowest nonzero mode has $\lambda_1^{\text{star}} = w$.

11.3 Transient predictions

The modal relaxation times from Eq. (6) are $\tau_n^{-1} = \Gamma(\kappa\lambda_n + \mu^2)$. The slowest modes satisfy

$$\frac{\tau_1^{\text{ring}}}{\tau_1^{\text{star}}} \approx \frac{\kappa w + \mu^2}{0.0979\,\kappa w + \mu^2}. \tag{43}$$

In the weak-screening regime $\mu^2 \ll \kappa w$, the star relaxes roughly ten times faster than the ring. This is a concrete, testable prediction arising purely from graph topology, not from mass.

11.4 Static predictions

For a uniform source $\rho_i = 1/20$ and an external coupling proxy $\Lambda_x(G) = B\sum_i u_i(G)/r_i$ with $u(G) = (\kappa L_w + \mu^2 I)^{-1}\rho$, the graph-pair prediction is

$$\Delta y_{\text{ring}-\text{star}}(x) \approx -\alpha B \sum_i \frac{u_i(C_{20}) - u_i(S_{20})}{r_i}. \tag{44}$$

Even with αB left symbolic, this is an explicit number once chip geometry and sensor height are specified.

11.5 Weight robustness

With weight disorder $w_{ij} = w_{ij}^{(0)} + \delta w_{ij}$, standard matrix perturbation theory gives eigenvalue shifts bounded by $|\delta\lambda_n| \le \|\delta L_w\|$. The nearly order-of-magnitude separation between the slowest ring and star modes survives moderate nonuniformity. What will not be robust are precise quantitative estimates of τ_n in heavily disordered devices; those require the full weight map.

12 The Experimental Program

12.1 The screening problem

In a tabletop geometry, the screened scalar profile takes the form

$$\Lambda(r) \sim G_{d_{\text{eff}}}(r)\, e^{-\mu r}. \tag{45}$$

For a vertical timing doublet with baseline $\Delta z \ll r$, the differential signal is

$$|\Delta y| \approx \alpha A \,\frac{\Delta z}{r^2} \qquad (\mu = 0), \tag{46}$$

and

$$|\Delta y| \approx \alpha A \,\frac{\Delta z}{r^2}\,(1+\mu r)\, e^{-\mu r} \qquad (\mu > 0). \tag{47}$$

The unscreened assumption is doing real work. On tabletop baselines, if $\mu r \gtrsim 1$, the signal is exponentially suppressed. Bounding or measuring μ from the distance law is therefore a first-class experimental objective, not an afterthought.

12.2 Sensitivity benchmarks

The precision-clock literature already reaches the regime where scalar timing effects are meaningful targets:

- **Demonstrated:** millimetre-scale gravitational redshift resolution in a lattice-clock sample [5].
- **Demonstrated methodology:** long-baseline clock/cavity comparison for weak coherent backgrounds [9].
- **Plausible near-term:** atomic clock interferometers and tweezer clock interferometers [6, 7].
- **Projected:** sub-millimetre differential redshift with spin squeezing at roughly 10^{-20} fractional sensitivity [8].

As an order-of-magnitude guide, if one can resolve differential fractional timing at the 10^{-19} level with $r \sim 1$ cm and $\Delta z \sim 1$ mm, then one is sensitive to $\alpha A_\Lambda \sim 10^{-20}$ m, up to order-one geometry factors.

12.3 Topology-versus-mass control ratio

A skeptical experimentalist is right to ask whether residual mass redistribution could imitate the timing signal. Define

$$R_{\text{topo/mass}} \equiv \frac{|\Delta y_{\text{topo}}|}{|\Delta y_{\text{mass}}|} \sim \frac{\alpha c^2}{G}\,\frac{\delta A_\Lambda}{\delta M}\, f_{\text{topo}}(1+\mu r)e^{-\mu r}. \tag{48}$$

The experiment is compelling only if the source design ensures either δM is extraordinarily small or δA_Λ is parametrically large compared with it. A useful graph-theoretic discriminator for the internal change is

$$D(G_1, G_2) = \frac{\|L_{w_1} - L_{w_2}\|_F}{\|L_{w_1}\|_F + \|L_{w_2}\|_F}. \tag{49}$$

12.4 Transient discriminant

The dynamical completion (6) gives mode timescales

$$\tau_n^{-1} = \Gamma(\kappa\lambda_n + \mu^2), \tag{50}$$

where λ_n are eigenvalues of L_w. If the source medium is toggled between internal states, the clock response should exhibit a transient made from relaxation times tied to the promoted-graph spectrum. A long tail or multiscale decay not matching the known thermal, electromagnetic, or servo time constants would be a powerful discriminant. The cryogenic environment itself generates transients—mechanical bursts can induce correlated errors on sub-millisecond scales [13], and thermal engineering changes relaxation behavior on sub-microsecond to microsecond scales [14]—so the distinction between graph-spectral and thermal transients is essential.

12.5 Six discriminants

A persuasive timing-first detection should satisfy as many of the following as possible:

1. **Distance-law discriminant:** the signal scales like Eq. (47), allowing an early bound on μ.
2. **Topology-versus-mass discriminant:** switching between nearly mass-matched internal states changes the timing signal by the predicted amount.
3. **Force-null discriminant:** colocated accelerometry and gradiometry remain consistent with the small residual-mass prediction while clocks show a larger structured signal.
4. **Anisotropy discriminant:** the timing pattern tracks source geometry or weighting network rather than only total mass.
5. **Temporal discriminant:** the signal exhibits a reproducible relaxation spectrum consistent with the graph-modal form and inconsistent with known environmental transients.
6. **Coherence discriminant:** synchronous differential readout across multiple clocks improves the signal in a way expected for a coherent scalar background but not for local technical noise.

A source-state change producing $|\Delta y_{\text{clock}}| \gg |\Delta y_{\text{mass}}|$ while all colocated force-level observables remain at or below the ordinary residual-mass expectation would not by itself overthrow GR. It would instead imply that the source medium carries an additional timing-like scalar sector not captured by ordinary mass redistribution.

12.6 Experimental architectures

12.6.1 Vertical clock doublet near a switchable medium

Two clocks vertically separated by Δz at mean distance r from a switchable source medium. The source is cycled between two internal states engineered to preserve total mass while changing internal weighting pattern. The signal is $\delta(\Delta y) \approx \alpha\Delta z\,\partial_z[\Lambda_{S_2} - \Lambda_{S_1}]$. For every candidate timing channel, differential controls—chip thermometry, microwave photon-noise monitoring, pulse-energy accounting, and mechanical/vibration monitoring—run in parallel.

12.6.2 Clock interferometer

A clock interferometer trades two separate sensors for one coherent device whose output is a proper-time phase. The scalar hypothesis predicts a phase shift $\delta\phi \sim \omega_0 \int dt\, \alpha\, \delta\Lambda(t)$, with $\delta\Lambda$ sourced by medium state changes.

12.6.3 Distributed clock network with null accelerometry

A network of clocks placed around the source medium, together with colocated accelerometers and environmental sensors, allows simultaneous testing of distance law, anisotropy, and force nulls.

13 First-Bound Proposal: Superconducting Arrays

The next healthy step in the program is to run the first severe experiment on an already existing reconfigurable graph medium and learn from the result. Tunable superconducting arrays are appropriate because real hardware already provides programmable couplings, nanosecond to sub-microsecond switching and gate times, and well-developed cryogenic control and readout [10, 11, 12].

13.1 Near-term sensor: integrated cryogenic phase sensor

The most feasible near-term sensor is not a free-standing optical lattice clock above a dilution refrigerator. It is a cryogenic phase-sensitive proxy integrated into the same cryostat: a spectator superconducting qubit in Ramsey mode, or a high-Q superconducting resonator monitored relative to a stable external microwave reference. This sensor shares many cryogenic and electromagnetic systematics with the source medium, so it is best treated as a first-bound experiment.

13.2 Stretch-goal sensor: external optical timing probe

The cleaner but harder architecture uses an external clock-grade sensor referenced through fiber or free-space optics to a transportable optical clock. Transportable Yb optical lattice clocks now exist [16], and cryogenic optical lattice clocks have reached blackbody-shift uncertainties at the 1.7×10^{-20} level [15]. But integrating an optical probe close to a dilution refrigerator while controlling vibration, thermal radiation, and line-of-sight access is a substantial engineering project for a follow-on experiment.

13.3 What a first bound should report

The experiment should report medium-specific bounds:

$$|\alpha A|_{\text{sc-array}} < \cdots , \qquad \mu_{\text{sc-array}} > \cdots , \qquad \Gamma_{\text{sc-array}} < \cdots \text{ or } > \cdots , \tag{51}$$

accompanied by explicit nuisance budgets for heating, microwave background, vibration, and package drift. A null result is already useful because it constrains the theory for a concrete medium class and guides the next medium-selection effort.

14 Numerical Closure Protocol

14.1 Workflow

The minimal numerical closure test proceeds in nine steps:

1. Extract or construct the promoted weighted graph W.
2. Compute L_w and the heat-kernel return probability $P_{\text{return}}(t)$.
3. Estimate $d_{\text{eff}}^{(\text{diff})}(t)$ from the slope.
4. Solve or measure the scalar field Λ and form shell averages.
5. Estimate $d_{\text{eff}}^{(\Lambda)}(r)$ from the shell profile.
6. Fit the timing law and record residuals across candidate windows.

7. Fit the static closure parameters (κ, μ, A).
8. If time-resolved data exist, fit the dynamical spectrum and compare with $\{\lambda_n\}$.
9. Repeat over system sizes, topologies, and extraction thresholds.

14.2 Outcome table

Numerical outcome	Interpretation
$d_{\text{eff}}^{(\text{diff})} \approx d_{\text{eff}}^{(\Lambda)} \approx 3$ and timing law fits best there	Strong internal support for the scalar-selection program
Dimension estimators agree but not near 3	Scalar closure may exist, but the selected branch is not Newton-like
Timing law fits but dimension estimators disagree	Scalar phenomenology exists but the dimensional-selection interpretation is incomplete
No clean Gaussian window	Chosen medium or extraction map does not support the intended regime
Dynamical spectrum tracks $\{\lambda_n\}$	Strong evidence for graph-mediated scalar dynamics
Dynamical spectrum does not track $\{\lambda_n\}$	Memory, thermal, or nonlocal corrections dominate

Table 2: Outcome interpretation table for numerical closure tests.

15 Failure Modes and Falsifiability

A truthful program is defined as much by its failure modes as by its ambitions. The identified failure modes include:

- Heavy-tailed or highly anisotropic weight distributions that destroy a Gaussian window.
- Bottlenecks or near-tree sparsity that prevent intermediate-scale diffusion from developing.
- Small-world shortcuts that create misleading crossover behavior in the dimension estimates.
- Source-placement dependence masquerading as a dimensional coincidence or plateau.
- Timing-law improvement in a different window from the dimension plateau.
- Screening so strong that any external signal is exponentially suppressed.
- Memory effects large enough that the Markovian closure is inadequate.
- External kernels dominated by thermal, substrate, or electromagnetic couplings rather than the scalar channel.
- An effectively null external kernel: the scalar load is internal only.
- Finite-size artifacts producing false plateaus that disappear under scaling.

These are not embarrassments. They are what allow the program to learn. A failure mode narrows scope while increasing truthfulness. If the same promoted operator does not control scalar response, effective dimension, and timing shifts in one common window, then the strongest version of scalar selection fails. If internal closure exists but external kernels are null or mundane, the claim shrinks to an internal medium observable sector. If only the timing law survives, then the dimensional-selection interpretation weakens. In each case the framework remains informative precisely because it is willing to lose pieces of itself.

16 Discussion

The deepest interpretive lesson of the present framework is modest: observable structure may be smaller than microscopic structure, and timing may be among the first stable survivors. That

claim is already nontrivial. It neither requires nor supports a rush to full emergent gravitation.

The paper does not presently establish a tensor or spin-2 sector, universal external scalar geometry, a derivation of cosmic three-dimensionality, a unique microscopic substrate, or a new force. What it does establish is a disciplined closure program in which internal scalar loads, external coupling kernels, medium realizability, and timing observables are treated separately and honestly.

The global-nonuniqueness lesson deserves emphasis. The recent construction of compact Bonnet pairs [19] shows that even in orthodox differential geometry, the same local metric and mean-curvature data can admit multiple global realizations. A scalar observable sector should therefore be interpreted as a constrained projection of global structure, not as a guaranteed decoder of the whole. Local observables are real, informative, and law-governed, yet may still underdetermine the realized global branch.

The program's broader thesis may be stated without ornament. A local graph substrate gives rise to promoted structure. Promoted structure defines a weighted Laplacian. The same Laplacian defines both a scalar response field and an effective dimension. In the appropriate scaling regime the scalar response obeys a Green-law radial profile, and the clock observable inherits that profile. The Newtonian weak-field branch appears as a conditional consequence when the effective dimension is near three within a Gaussian scaling window. Independent dimensional-stability arguments then show why this value is not merely convenient but viable.

Within this picture, observable three-dimensionality and the familiar weak-field branch are conditional outcomes of the closure—selected by dimensional survivability within a Gaussian scaling window, not derived as necessary features of all possible substrates. If the program fails, it will fail at one of the closure tests enumerated in this paper, and each such failure will narrow scope while increasing truthfulness.

17 Conclusion

We have formulated an integrated closure program for systems in which a scalar response sector may be the first stable geometric observable to survive coarse graining. The framework rests on four components: an effective weighted graph, a leading screened weighted-Laplacian closure for a scalar load, a timing law coupling that load to local clock rates, and a pair of independent dimension estimators derived from the same operator structure. Its decisive test is not any one of these pieces in isolation, but their coincidence in a common scaling window.

The microscopic route from coupler physics in reconfigurable superconducting networks to the screened weighted-Laplacian closure has been derived via Markovian Schur-complement elimination of fast coupler variables. A concrete worked example—a 20-node ring versus star—generates explicit transient and static predictions that differ by nearly an order of magnitude due to graph topology alone. Five classes of internal-to-external coupling kernels have been classified, with the null kernel acknowledged as a legitimate outcome. A six-discriminant experimental program, complete with magnitude estimates, topology-versus-mass control ratios, and sensitivity benchmarks from the current precision-clock literature, provides a concrete path to the first empirical bound.

The program is intentionally narrow. It does not assume full metric emergence, tensor completion, or automatic external accessibility. It requires that internal scalar loads, external coupling kernels, medium realizability, and timing observables all be treated separately and honestly. If the same promoted operator controls scalar response, effective dimension, and timing shifts in one real medium class, then a scalar timing geometry will have ceased to be a suggestive metaphor and become a real observable sector. If not, the theory will have constrained itself. Either result would be progress.

A Notation Registry

Symbol	Meaning	Level	Role
H_{micro}	Microscopic Hamiltonian	Microscopic	Node, coupler, and drive dynamics
$W = (w_{ij})$	Weighted adjacency matrix	Mesoscopic	Effective programmable graph
D	Degree matrix, $D_{ii} = \sum_j w_{ij}$	Mesoscopic	Builds Laplacian from weights
$L_w = D - W$	Weighted graph Laplacian	Effective	Operator controlling diffusion and scalar response
ρ	Effective source density	Effective	Source from graph switching or bias
Λ_i	Internal scalar load	Effective observable	Primary retained scalar quantity
$\Lambda(r)$	Shell-averaged scalar load	Effective observable	Long-distance profile for closure tests
$\Lambda_{\text{ext}}(x)$	External scalar load	Effective observable	Quantity at external sensor
$C(x, i)$	Coupling kernel	Effective coupling	Maps internal load to external probe
κ	Stiffness coefficient	Effective parameter	Graph-mediated smoothing strength
μ	Screening scale	Effective parameter	Finite penetration depth
A	Source amplitude	Effective parameter	Source-to-response conversion
Γ	Relaxation rate	Effective dynamical	Sets timescales in dynamical completion
d_{eff}	Effective spectral dimension	Geometric observable	From return-probability or shell-profile scaling
$G_{d_{\text{eff}}}(r)$	Effective Green kernel	Geometric	Asymptotic radial behavior of $\Lambda(r)$
ω	Bare clock frequency	Observable baseline	Reference before scalar loading
ω_{eff}	Effective local frequency	Observable	Shifted by scalar load
α	Clock susceptibility	Observable parameter	Converts load to timing shift
Δy	Fractional timing shift $\delta\omega/\omega$	Experimental	Main quantity for timing-first searches

Table 3: Notation registry with level assignments. When interpreting any claim, the reader should ask: is the symbol microscopic, effective, or directly observable? Is the claim structural, numerically testable, medium-specific, or experimental?

B Claim Registry

A. Structural claims internal to the framework.

- A graph-mediated scalar sector can be represented at leading order by a screened weighted-Laplacian closure.
- The same promoted graph that carries scalar response can define an effective spectral dimension.
- Timing-first observables are the natural first probes of the scalar sector.

B. Claims requiring direct numerical closure.

- Agreement of diffusion-based and shell-profile-based dimension estimates: $d_{\text{eff}}^{(\text{diff})} \overset{?}{\approx} d_{\text{eff}}^{(\Lambda)} \overset{?}{\approx} 3$.
- Existence of a stable intermediate scaling window supporting the Gaussian regime.
- Robust extraction of μ and the modal relaxation spectrum.

C. Claims requiring medium-specific derivation.

- Mapping from microscopic device parameters to W, ρ, and Λ.
- Derivation of the internal-to-external kernel $C(x, i)$.
- Quantitative prediction of timing residuals for a specific hardware platform.

D. Claims requiring experiment.

- Any nonzero timing-first signature.
- Any measurable screening length in a real source medium.
- Any topology-versus-mass separation in a controlled null experiment.

C Medium Selection Criteria

A viable source medium should support:

1. a meaningful weighted-graph extraction,
2. reconfigurable or controllable internal structure,
3. differential timing or phase readout,
4. moderate disorder rather than destructive inhomogeneity,
5. transient and static channels distinguishable from obvious nuisance signals,
6. bounded-degree or effectively bounded-degree internal coupling,
7. moderate homogeneity under reconfiguration (not dominated by weight disorder or shortcuts that destroy a clean Gaussian window).

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