Timing Before Force:
A Quantitative Experimental Program for Scalar-First Geometry

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Abstract

We formulate a quantitative experimental program for the hypothesis that the first observable geometric sector is scalar and timing-like rather than tensor and force-like. The working model is a promoted weighted graph whose coarse-grained scalar load Λ obeys a screened Green-response closure and renormalizes local clock rates by $\omega_{\text{eff}} = \omega/(1+\alpha\Lambda)$. We derive distance-law, topology-control, and transient-response discriminants for tabletop tests. The key near-term target is a timing perturbation without a corresponding force-level signature. We show explicitly that the unscreened assumption is doing substantial work in magnitude estimates; if the screening scale μ^{-1} is not long compared with the experimental baseline, the signal is exponentially suppressed. We therefore elevate an early bound on μ to a first-class experimental objective. We also derive a temporal discriminant: if the scalar sector is governed by promoted-graph diffusion, then state switching of the source medium should produce a relaxation spectrum set by the low-lying modes of the same weighted Laplacian that defines the effective dimension. The paper concludes with concrete source-medium requirements, quantitative control ratios for topology-vs-mass discrimination, and reference-linked sensitivity benchmarks from recent clock and interferometry literature.

1. Premise

The present paper takes seriously a narrow but falsifiable possibility: a structured medium may source a scalar timing perturbation before any full tensor or force-level signature is visible. The hypothesis is not that general relativity is wrong in its domain, but that there exists an earlier observable sector in which the operational variable is clock rate rather than acceleration. In the underlying scalar-first program, the effective clock law is

$$\omega_{\text{eff}}(x) = \frac{\omega}{1+\alpha\Lambda(x)}, \qquad \frac{d\tau}{dt} = \frac{1}{1+\alpha\Lambda(x)}. \tag{1}$$

In the weak-load limit,

$$\frac{\delta\omega}{\omega} \approx -\alpha\Lambda(x). \tag{2}$$

The experimental question is whether there exist source media for which the measurable timing signal implied by (**??**) exceeds or qualitatively outruns any conventional force-level interpretation.

2. Screened scalar closure and why μ matters

The scalar load is modeled as the response of a promoted weighted graph to a source profile ρ:

$$(\kappa L_w + \mu^2 I)\Lambda = A\rho. \tag{3}$$

Here $L_w = D - W$ is the weighted graph Laplacian of the promoted internal structure, $\kappa > 0$ sets the stiffness of the scalar sector, A sets source strength, and μ is a screening scale. If $\mu = 0$, the response is unscreened and the far-field kernel follows the effective Green law of the promoted geometry. If $\mu > 0$, then at distances $r \gtrsim \mu^{-1}$ the scalar profile crosses over to Yukawa-like suppression,

$$\Lambda(r) \sim G_{d_{\text{eff}}}(r) e^{-\mu r}, \tag{4}$$

so the magnitude estimates of this paper collapse exponentially if the experiment operates outside the unscreened window.

This point deserves emphasis. In a tabletop geometry the baselines are short but not negligible; if μ^{-1} is comparable to source–sensor separation, then the apparent scalar timing signal may vanish even when the unscreened theory would predict detectability. The distance-law discriminant is therefore not merely a side check. It is an essential first measurement. A successful program should treat a bound on μ—or a detection of the transition from power-law to screened response—as one of its earliest objectives.

3. Distance law and baseline timing signal

For the effective three-dimensional branch, the unscreened scalar profile takes the form

$$\Lambda(r) \approx \frac{A_\Lambda}{r}, \tag{5}$$

so a vertical differential clock measurement across separation $\Delta z \ll r$ gives

$$\Delta y \equiv \frac{\Delta\omega}{\omega} \approx \alpha |\partial_z \Lambda| \, \Delta z \approx \alpha A_\Lambda \frac{\Delta z}{r^2}. \tag{6}$$

With screening,

$$\Delta y \approx \alpha A_\Lambda \frac{\Delta z}{r^2}(1 + \mu r) e^{-\mu r}, \tag{7}$$

up to order-one geometric factors set by source placement.

Equation (**??**) is the operational baseline. Every magnitude claim in the experimental program should be understood as implicitly assuming $\mu r \ll 1$ unless explicitly stated otherwise.

4. Sensitivity benchmarks and what is achieved vs projected

The broader clock literature already reaches the regime where scalar timing effects are meaningful experimental targets. A 2021 Nature experiment resolved gravitational redshift across a millimetre-scale atomic sample using an optical lattice clock, establishing that millimetre-scale differential timing is already a demonstrated capability [**?**]. A 2024 analysis of single-photon atomic-clock interferometers developed explicit gravitational-redshift sensitivity in clock-interferometric language

[?]. A 2024 optical-tweezer clock-interferometry proposal showed feasible linear sensitivity to gravitational time dilation with current capabilities [?]. A 2025 study argued that spin squeezing could extend gravitational-redshift resolution to sub-millimetre separations at the 10^{-20} fractional level, but this is a proposal rather than an achieved experimental demonstration [?]. A 2025 optical-lattice-clock theory paper explored the dynamical interplay between mass-energy equivalence, interactions, and entanglement in a clock medium [?]. Finally, a 2025 PRL demonstrated the use of space-time separated clocks and cavities as coherent distributed sensors for weak scalar backgrounds [?].

For clarity, the benchmarks relevant here are:

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

5. The source medium problem

The weakest link in the present program is not the clock. It is the medium. The source must change the retained scalar observable algebra without producing an ordinary gravitational or electromagnetic signature large enough to trivially explain the data.

A viable medium should have the following properties:

1. a reconfigurable internal network of couplings, so that a weighted Laplacian description is meaningful;
2. at least two controllable internal states with nearly matched ordinary mass distribution but different internal weighting patterns;
3. switchability on laboratory timescales;
4. low thermal and electromagnetic cross-talk to nearby precision clocks;
5. a plausible route to identifying an effective source density ρ and a response kernel for Λ.

Two natural starting points are superconducting circuit networks and optical-lattice / tweezer clock media. The former offer tunable connectivity and phase-coherent internal structure; the latter offer clock-native readout and controllable interaction graphs. But neither option yet gives a complete first-principles derivation from microscopic degrees of freedom to Eq. (??). That mapping remains the hardest next paper.

6. Experimental architectures

6.1. Vertical clock doublet near a switchable medium

Place two clocks vertically separated by Δz at mean distance r from a switchable source medium. The source is cycled between two internal states, S_1 and S_2, engineered to preserve total mass and low ordinary multipoles as closely as possible while changing internal weighting pattern. The timing-first signal is

$$\delta(\Delta y) \approx \alpha\, \Delta z\, \partial_z(\Lambda_{S_2} - \Lambda_{S_1}). \tag{8}$$

The crucial control is the ratio of topology-dependent to residual mass-dependent contribution. Write

$$\delta(\Delta y) = \delta(\Delta y)_{\rm topo} + \delta(\Delta y)_{\rm mass}. \tag{9}$$

For a residual mass redistribution δM at the same baseline, the ordinary GR contribution is approximately

$$\delta(\Delta y)_{\rm mass} \sim \frac{G\,\delta M}{c^2}\frac{\Delta z}{r^2}. \tag{10}$$

The scalar contribution is

$$\delta(\Delta y)_{\rm topo} \sim \alpha\, \delta A_\Lambda\, f_{\rm topo}\frac{\Delta z}{r^2}(1+\mu r)e^{-\mu r}, \tag{11}$$

where $f_{\rm topo}$ is an order-one geometry factor and δA_Λ is the effective source change between internal states. Thus

$$R_{\rm topo/mass} \equiv \frac{|\delta(\Delta y)_{\rm topo}|}{|\delta(\Delta y)_{\rm mass}|} \sim \frac{\alpha c^2}{G}\frac{\delta A_\Lambda}{\delta M} f_{\rm topo}(1+\mu r)e^{-\mu r}. \tag{12}$$

This is the quantity the medium must win on. A skeptical experimentalist is right to ask whether residual mass redistribution at the $\delta M/M$ level could imitate the timing signal. Equation (**??**) is the answer: the source design must ensure either δM is extraordinarily small or δA_Λ is parametrically large compared with it.

6.2. Clock interferometer geometry

A clock interferometer is attractive because it trades two nominally separate sensors for one coherent device whose output is a proper-time phase. The scalar hypothesis predicts a phase shift of the form

$$\delta\phi \sim \omega_0 \int dt\, \alpha\, \delta\Lambda(t), \tag{13}$$

with the crucial distinction that $\delta\Lambda$ may be sourced by medium state changes even when no conventional force signal is visible at the same level. This architecture is appealing for temporally modulated source studies.

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. The target signature is a reproducible pattern in the clock network that tracks source state but is not mirrored by local acceleration, magnetic pickup, or thermal phase shifts.

7. Transient response: the missing discriminant

The temporal signature is potentially as valuable as the static one. If the scalar load is tied to promoted-graph reorganization, then source-state switching should not necessarily look instantaneous in the readout channel. A natural dynamical completion of Eq. (**??**) is a diffusion-relaxation equation,

$$\partial_t \Lambda + \Gamma(\kappa L_w + \mu^2 I)\Lambda = \Gamma A \rho(t), \tag{14}$$

with mode decomposition

$$\Lambda(t) = \sum_n c_n(t)\phi_n, \qquad \tau_n^{-1} = \Gamma(\kappa\lambda_n + \mu^2), \tag{15}$$

where λ_n are eigenvalues of L_w.

This gives a concrete prediction. If the source medium is toggled between internal states, the clock response should exhibit a transient made from one or more relaxation times tied to the same promoted-graph spectrum that defines the effective dimension. A long tail or multiscale decay not matching the known thermal, electromagnetic, or servo time constants of the apparatus would be a powerful discriminant. In particular, the slowest mode is

$$\tau_{\mathrm{rel}} \sim \frac{1}{\Gamma(\kappa\lambda_1 + \mu^2)}, \tag{16}$$

so screening and graph connectivity both affect how quickly the scalar load reorganizes. This is the temporal analogue of the distance-law measurement and should be treated as a core observable, not an afterthought.

8. Discriminants

A persuasive timing-first detection should not rely on one signature. It should satisfy as many of the following discriminants as possible.

1. **Distance-law discriminant**: the signal scales like Eq. (**??**), allowing an early bound on μ.
2. **Topology-vs-mass discriminant**: switching between nearly mass-matched internal states changes the timing signal by the amount predicted in Eq. (**??**).
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 or tail consistent with Eq. (**??**) 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.

9. What would count as distinguishable from standard GR?

Standard weak-field GR ties the clock signal and force signal to the same potential sourced by ordinary mass-energy. In the present program, the distinguishing possibility is narrower: a source-state change that produces

$$|\delta(\Delta y)_{\mathrm{clock}}| \gg |\delta(\Delta y)_{\mathrm{mass}}| \tag{17}$$

while all colocated force-level observables remain at or below the ordinary residual-mass expectation. Such a result 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.

10. Early-stage magnitude targets

For the unscreened $d_{\mathrm{eff}} \approx 3$ branch, Eq. (**??**) implies

$$\alpha A_\Lambda \sim |\Delta y| \frac{r^2}{\Delta z}. \tag{18}$$

As an order-of-magnitude guide, if one can resolve differential fractional timing at the 10^{-19} level with $r \sim 1\,\mathrm{cm}$ and $\Delta z \sim 1\,\mathrm{mm}$, then one is sensitive to

$$\alpha A_\Lambda \sim 10^{-20}\,\mathrm{m} \tag{19}$$

up to order-one geometry factors. A realistic experimental design should immediately translate its geometry and achieved stability into an equivalent bound on αA_Λ and, separately, on the screening length μ^{-1}.

11. Conclusion

The timing-first program is now sharp enough to fail. That is a virtue. The theory predicts not merely that clocks are sensitive, but that there should exist a regime in which structured timing perturbations appear before corresponding force-level signatures, provided the source medium changes an internal promoted-graph weighting pattern more strongly than it changes ordinary mass multipoles. The unscreened assumption is doing real work in the size of the predicted signal, so bounding or measuring the screening scale μ is a critical early objective. The temporal response is also elevated to a primary observable: if the same promoted graph governs both effective dimension and scalar response, then its low-lying diffusion modes should appear in the transient clock signal when the medium is switched. The hardest remaining problem is the medium itself. Solving that is likely the next paper.

References

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