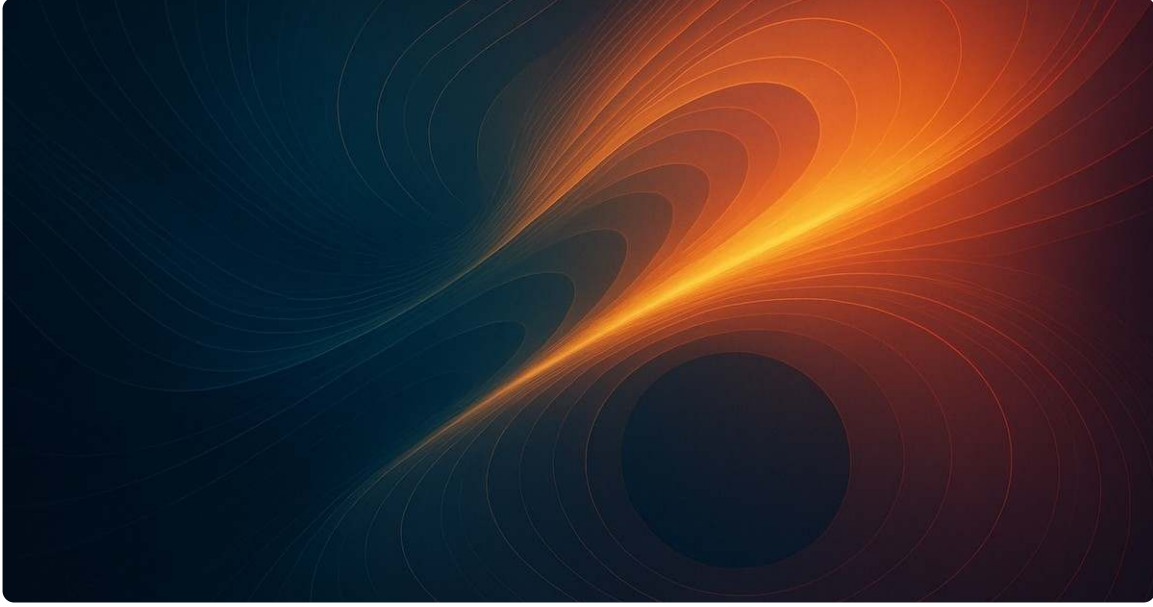




Temporal Equivalence Principle: Dynamic Time & Emergent Light Speed

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Abstract

This paper proposes a covariant, testable reformulation of relativity in which proper time is a dynamical field and the "speed of light" is an emergent, strictly local invariant rather than a global constant. The framework is built on a single spacetime manifold endowed with two metrics: a gravitational metric $g_{\mu\nu}$ and a causal (matter) metric $\tilde{g}_{\mu\nu}$ to which all non-gravitational fields and clocks couple. In isotropic shorthand the metrics are related by a controlled disformal map, $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu} + B(\phi)\nabla_\mu\phi\nabla_\nu\phi$, where ϕ is the time field, $A(\phi) = \exp(\beta_A\phi/M_{Pl})$ is a universal conformal factor, and $B(\phi)$ encodes tiny, direction-dependent deformations of the light cone consistent with GW170817-class multi-messenger constraints ($|c_\gamma - c_g|/c \lesssim \text{few} \times 10^{-15}$ today); decomposed along the unit cosmic temporal flow $U_\mu \equiv -\nabla_\mu\tilde{\phi}/\sqrt{2\tilde{X}}$ ($g^{\mu\nu}U_\mu U_\nu = -1$, orthogonal spatial projector $\Pi_{\mu\nu} = g_{\mu\nu} + U_\mu U_\nu$), this resolves into $\tilde{g}_{\mu\nu} = -A_{loc}^2(u_{grav})U_\mu U_\nu + A_{sp}^2(u_{drift})\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha\Pi_\nu^\beta\nabla_\alpha\phi\nabla_\beta\phi$, separating the stationary baryon-sourced ADM lapse $N_{TEP}(\mathbf{x}) = A_{loc}(u_{grav}(\mathbf{x}))N_{GR}(\mathbf{x})$ from the secular matter-frame spatial ruler factor $A_{sp}(u_{drift}(t, \mathbf{x})) = \exp(-u_{drift}(t, \mathbf{x}))$ on static gravitational 3-space $\gamma_{ij}(\mathbf{x})$. Proper time is elevated to a field by postulating that all matter, electromagnetism, and quantum phases evolve with respect to $\tilde{g}$ -proper time τ ; in local freely falling frames, this guarantees exact local Lorentz invariance and a locally invariant c , while globally it implies that synchronization procedures and one-way light-time measurements can become path-dependent in the disformal/non-exact sector of a dynamical-time background. The covariant action, field equations, conservation laws, and PPN mapping are developed; screening is formulated via continuous Temporal Topology and nonlinear Temporal Shear ($P_{,X} = k\sqrt{\xi} + 2\xi$, $k \simeq 16$ fixed by α_0). The breakdown of global simultaneity is formalized using a synchronization-transport law, deriving a convention-independent "synchronization holonomy," an invariant measure of non-integrability of time transport around closed loops. In the purely conformal subclass this holonomy vanishes after subtraction of the full GR, kinematic, clock-scale, and reference-frame synchronization model; nonzero holonomy at leading order requires residual non-exact synchronization structure, supplied in the minimal TEP model by disformal coupling $B(\phi) \neq 0$, and in more general extensions by non-metricity or other explicitly non-exact transport structure. Explicit small- B formulas are provided for the holonomy and the effective photon phase speed, showing how the measured one-way asymmetry is related to ϕ -gradients and disformal scales under current constraints. The analysis demonstrates that Einstein's assumption of a universal c was a brilliant local theorem arising from the Temporal Equivalence Principle; transcending it demands dynamical time: c remains exactly invariant locally, but global, one-way-inferred " c " values differ by path-dependent amounts that experiments can detect or bound. Cosmologically, TEP adopts an eternal, spatially infinite, inhomogeneous background whose physical volume does not undergo cosmological expansion. Neither space nor matter changes size. The matter unit of time drifts relative to the static gravitational geometry (γ_{ij}), and because c is locally invariant, the matter unit of length drifts with it (A_{sp}). Distances and

densities expressed in matter units therefore evolve without any physical stretching, allowing the observed redshift and apparent Hubble relation to emerge directly from the macroscopic historical drift of the inhomogeneous temporal network over coordinate time, governed principally by the conformal endpoint ratio $1 + z = A_{\text{sp}}(t_o)/A_{\text{sp}}(t_e)$, with constrained non-exact propagation corrections through the temporal topology. An exactly solved closed-static branch establishes that the specified action admits a static, eternal gravitational configuration with conformal unit drift; that branch is an analytical benchmark, neither an attractor nor capable of near-flat matter geometry. Numerical noncompact solutions now demonstrate a constraint-consistent, on-shell inhomogeneous temporal landscape with near-zero native matter-frame spatial curvature ($|\Omega_k^{\text{native}}| = 1.40 \times 10^{-4}$), sustained secular temporal roll, and a positive-definite linear fluctuation spectrum on the gauge-constrained physical subspace ($\lambda_1 = +38.96$ at $N = 24$ and $+39.06$ at $N = 32$ on the canonical branch; $\lambda_1 = +555.35$, $\omega_1 = 23.57$ at $N = 24$ and $+551.66$ at $N = 32$ on the selected two-branch kinetic sector; supplemented by an independent discrete lower bound on the ambient branch, complete matter-coupling second-variation positivity $\lambda_0 = +0.4123\text{--}0.4127 > 0$ and joint on-shell quartic positivity $\lambda_0 = +0.5624\text{--}0.5633 > 0$ without homogeneous-mode projection, an all-twist Bloch lower bound $\lambda \geq \min m_{\text{eff}}^2 > 0$, and a positive evolving constant-mean-curvature initial-slice lapse solution); the remaining cosmological closure is quantitative: fixing the universal master-potential branch such that the evolved temporal history reproduces the observed redshift–distance relation, horizon behaviour, and perturbation observables without imposing the empirical clock map. A candidate early-universe closure, in which the Big Bang gravitational singularity is replaced by a matter-frame temporal boundary without phenomenological thermal screening, is developed through the companion transport analyses (TEP-TH, TEP-BBN, TEP-HC), whose conformal temporal geometry preserves the observed CMB acoustic structure. Known weaknesses in the variable- c literature are addressed by supplying a correct, operationally invariant observable (holonomy), clarifying when conformal couplings cannot produce a signal, and providing realistic, constraint-consistent benchmark sensitivity windows with explicit error budgets and statistical plans (pre-registration, blinding, publicly released code and data). The resulting theory preserves the empirical pillars of relativity (local Lorentz invariance, gravitational-wave causality, PPN bounds) while extending its conceptual foundation: simultaneity is not only relative but generally non-integrable; the speed of light is not a global constant but the local echo of a deeper, dynamical temporal geometry.

Long-standing confusions about "variable c " are resolved by replacing convention-dependent statements with invariant observables tied to measurement procedures. A synchronization one-form $\tilde{\sigma}$ is defined on spacelike slices of the matter metric; its curl $d\tilde{\sigma}$, after subtraction of the full GR, kinematic, clock-scale, and reference-frame synchronization model, yields a residual "temporal holonomy" H_{resid} that vanishes in GR and becomes nonzero only when time is dynamical in this sense. Embedding the preferred-foliation geometry in a spatially covariant ADM/khronon effective action establishes four key results: (i) conformal matter coupling preserves null cones, and electromagnetic waves and transverse-traceless gravitons share the identical principal wave operator $\square_{\text{TEP}} \equiv -(N_{\text{TEP}}c)^{-2}\partial_t^2 + A_{\text{sp}}^{-2}(t, \mathbf{x})\gamma^{kl}\partial_k\partial_l$, enforcing $c_{\text{GW}}(t, \mathbf{x}) = c_\gamma(t, \mathbf{x})$ at every event ($\Delta t_{\gamma\text{--GW}} \equiv 0$ at $B = 0$, satisfying GW170817); (ii) the static-space WKB tensor measure $\sqrt{A_{\text{sp}}^{+1} \cdot A_{\text{sp}}^{-1}} \equiv 1$ eliminates FLRW Hubble friction, preserving $1/r$ graviton decay, the standard-siren discriminator $\Xi(z) = d_L^{\text{GW}}/d_L^{\text{EM}} = 1/(1+z)$, and the inverse detector chirp-mass map $\mathcal{M}_{\text{det}} = \tilde{\mathcal{M}}/(1+z)$ at pinned interior response; (iii) a static ϕ -gradient produces no direct propagation asymmetry in the static purely conformal limit—the cancellation is exact, not merely first-order; and (iv) the selected two-branch kinetic sector ($P_{,X} = k\sqrt{\xi} + 2\xi$, $k \simeq 16$ derived from $a_0 \sim cH_0$) screens Solar-System post-Newtonian observables ($|\gamma_{\text{PPN}} - 1| \simeq 4.32 \times 10^{-8}$ at $1.6 R_\odot$), lunar laser ranging ($|\dot{G}_{\text{loc}}/G_{\text{loc}}|_{\text{LLR}} \lesssim 1.7 \times 10^{-18} \text{ yr}^{-1}$), and binary-pulsar dipole radiation well inside observational bounds while passing the wide-binary joint test at $0.4\text{--}1.7\sigma$ with zero per-system free parameters and generating flat galactic rotation curves and unstretched-space gravitational lensing via $A_{\text{loc}}(u_{\text{grav}})$. Disformal tilts ($B \neq 0$) can source holonomy subject to multi-messenger constraints. A corrected Earth–Sun triangle calculation gives a converged conditional benchmark $|H_{\text{resid}}| \simeq 4.33 \times 10^{-13} \text{ s}$ per loop, with zero circulation in the exact-connection control. The normalization and environmental response remain specified benchmark inputs; an absolute TEP prediction requires their derivation from the common action and field solution. The effective covariant architecture is presented; field equations, conservation laws, invertibility/causality conditions, and a 3+1 decomposition are derived to make the observables explicit. Screening via a continuous Temporal Topology governed by non-linear superposition of field gradients (Temporal Shear) reconciles precision local tests with cosmological evolution, with mapping to Parametrized Post-Newtonian parameters and to the EFT-of-dark-energy α -functions with $c_T = 1$ enforced. Decisive experiments with quantitative error budgets are outlined: (1) a ground–ground–satellite triangle time-transfer experiment targeting holonomy at below 10^{-18} fractional after GR subtraction; (2) portable-clock "clock anholonomy" around closed paths at the 10^{-19} level over days; (3) multi-species clock networks seeking phase-locked annual modulations at $10^{-19}\text{--}10^{-17}$; (4) interplanetary one-way optical links at picoseconds over AU; (5) altitude-dependent screening maps with optical clocks and atom interferometers; and (6) ensemble multi-messenger tests. Cosmological inference is implemented through native `hi_class` and `Cobaya` analyses (Papers 18, 26), with commitment to open data and blinded analyses.

Einstein's postulate of universal c was a brilliant, operationally perfect approximation in regimes where time's flow is effectively uniform. In a universe where the rate of time is dynamical yet locally Lorentzian, "the speed of light" emerges as an invariant in every local lab but ceases to be globally universal. The new invariant content resides in path-dependent

synchronization defects and holonomies of time transport, not in naive one-way "speeds." If detected, these invariants would inaugurate a post-Einsteinian era: from dynamic geometry to dynamic time.

1. Introduction: From a Universal Speed to a Universal Principle of Time

Relativity and quantum theory disagree about time. General relativity (GR) makes proper time geometric— $d\tau^2 = -g_{\mu\nu}dx^\mu dx^\nu/c^2$ —dynamical, and observer-dependent. Quantum mechanics (QM) treats time as an external parameter t in the Schrödinger equation, $i\hbar\partial_t|\psi\rangle = \hat{H}|\psi\rangle$. The clash has haunted quantization programs for a century and manifested operationally as subtle ambiguities in defining one-way light speeds and simultaneity across extended regions. Precision clocks and time-transfer links now measure gravitational redshifts and velocity-dependent dilations at 10^{-18} fractional levels, while cosmology exhibits persistent H_0 and S_8 tensions. In this context, Einstein's postulate of a universal speed c must be sharpened: it is exact for any local freely falling laboratory, but it cannot be a global property if the flow of time itself is dynamical.

The Temporal Equivalence Principle (TEP) is proposed: all non-gravitational dynamics, signals, and quantum phases evolve according to the proper time defined by a single causal metric $\tilde{g}_{\mu\nu}$ that couples universally to matter. The rate at which proper time accrues is a field. This elevates "when" to the status "where" acquired in 1915: as space was geometrized, now time's rate is dynamized. The consequence is that synchronization conventions can become globally non-integrable when the dynamical-time background contains a disformal or otherwise non-exact transport component: even after removing known GR effects, closed-loop time transport can then retain a residual path-dependent offset. The measured "speed of light" between distant clocks is revealed as an emergent ratio of distance to accrued proper time, not a fundamental constant comparable across regions without a theory of time's flow. Locally, c remains exactly invariant; globally, dynamical time imprints tiny, path-dependent asymmetries that can be detected or bounded.

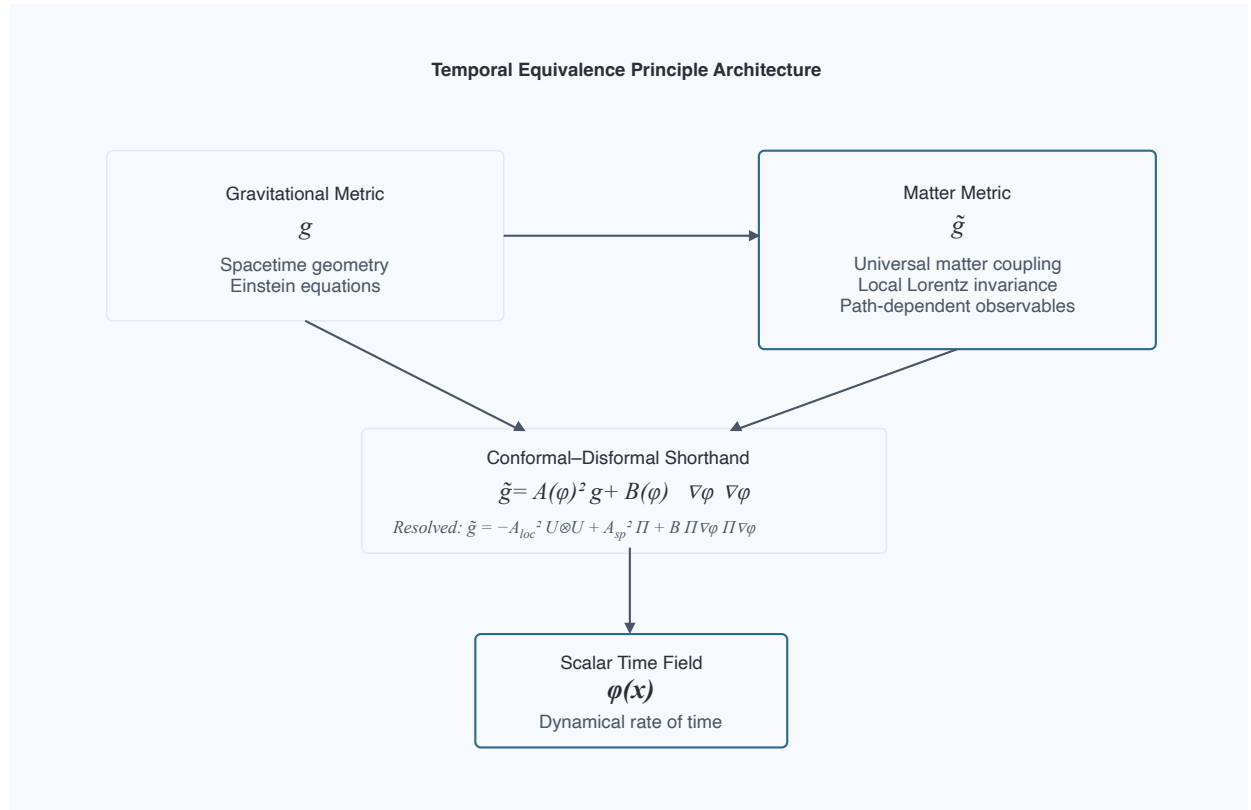


Figure 1. Temporal Equivalence Principle (TEP) architecture. Matter couples to $\tilde{g}_{\mu\nu}$ via a conformal-disformal map controlled by the scalar time field ϕ (shown in both isotropic shorthand and the resolved preferred-foliation (A_{loc}, A_{sp}) decomposition of §2.2), preserving local Lorentz invariance while enabling new global invariants.

2. Axioms and the Temporal Equivalence Principle

The framework adopts four axioms:

A1. Two-metric structure on a single manifold. Gravity is described by a Lorentzian metric $g_{\mu\nu}$; matter fields, clocks, and rulers couple to a causal (matter) metric $\tilde{g}_{\mu\nu}$. Decomposing the scalar time field along the cosmic temporal flow

$U_\mu \equiv -\nabla_\mu \tilde{\phi} / \sqrt{2\tilde{X}}$ ($g^{\mu\nu}U_\mu U_\nu = -1$, orthogonal spatial projector $\Pi_{\mu\nu} = g_{\mu\nu} + U_\mu U_\nu$) into the stationary baryon-sourced temporal-depth perturbation $u_{\text{grav}}(\mathbf{x})$ and the secular ruler-drift sector $u_{\text{drift}}(t, \mathbf{x})$, the metrics are related by the single unified map

$$\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x})) U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x})) \Pi_{\mu\nu} + B(\phi) \Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi, \quad (1)$$

with local lapse factor $A_{\text{loc}}(u_{\text{grav}}) = \exp(\beta_A u_{\text{grav}}) = \exp(-u_{\text{grav}}(\mathbf{x}))$ ($\beta_A = -1$, so

$N_{\text{TEP}}(\mathbf{x}) = A_{\text{loc}}(u_{\text{grav}}(\mathbf{x})) N_{\text{GR}}(\mathbf{x})$, matter-frame spatial ruler factor $A_{\text{sp}}(u_{\text{drift}}) = \exp(\beta_A u_{\text{drift}}) = \exp(-u_{\text{drift}}(t, \mathbf{x}))$ on static gravitational 3-space $\gamma_{ij}(\mathbf{x})$ ($d\tilde{s}^2 = -N_{\text{TEP}}^2(\mathbf{x})c^2 dt^2 + A_{\text{sp}}^2(t, \mathbf{x})\gamma_{ij}(\mathbf{x})dx^i dx^j$), and a small spatial disformal function $B(\phi)$ consistent with multi-messenger constraints today. On the homogeneous IGM background ($u_{\text{grav}} = 0$, $\Pi_\mu^\alpha \nabla_\alpha \phi = 0$, $\dot{u}_{\text{drift}} = -H_{\text{drift}} < 0$) this governs cosmological ruler drift $1 + z = A_{\text{sp}}(t_o)/A_{\text{sp}}(t_e)$; at a fixed cosmic epoch inside a screened system ($A_{\text{sp}}(t_0) = 1$) it reduces identically to the unstretched-space temporal metric $\tilde{g}_{\mu\nu} = g_{\mu\nu} - (A_{\text{loc}}^2(u_{\text{grav}}) - 1)U_\mu U_\nu + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ with $\tilde{\gamma}_{ij} = \gamma_{ij} = (1 - 2\Phi_N/c^2)\delta_{ij}$.

A2. Temporal Equivalence Principle (TEP). All non-gravitational processes evolve according to proper time $d\tau$ defined by $\tilde{g}_{\mu\nu}: i\hbar d|\psi\rangle/d\tau = \hat{H}|\psi\rangle$, nongravitational fields propagate on $\tilde{g}$ -null cones, and ideal clocks tick $d\tau^2 = -\tilde{g}_{\mu\nu}dx^\mu dx^\nu/c^2$. In local freely falling frames for $\tilde{g}_{\mu\nu}$, physics reduces to special relativity with invariant c .

A3. Causal safety and locality. Today, $c_g = c_\gamma$ within current bounds ($|c_g - c_\gamma|/c \lesssim \text{few} \times 10^{-15}$). This is enforced by choosing $A(\phi)$ universal, such that conformal transformations preserve null cones for photons and gravitons when $B = 0$, and by constraining the observable combination $B(\phi)(\partial\phi)^2$ along late-time astrophysical propagation paths. Different experiments constrain different integrals or responses involving the single disformal function $B(\phi)$; GW170817 does not require B to vanish identically in all regimes. Hyperbolicity holds within the EFT domain. On the admissible kinetic branch ($P_X > 0$, $P_X + 2XP_{,XX} > 0$) the scalar stress tensor obeys the null energy condition pointwise, $T_{\mu\nu}k^\mu k^\nu = P_X(k \cdot \nabla\phi)^2 \geq 0$; the weak and dominant conditions are violated in the void sector of the eternal static solution, where the integrability condition of Section 8 requires a negative cell-averaged effective energy density supplied by the potential rather than by a wrong-sign kinetic term (Appendix E, step_20: void-sector mean -0.58 , cell mean -0.52 in slice units).

A4. Screening and universality. The coupling $A(\phi)$ is universal at leading order; loop-induced composition dependence is tightly bounded. Environmental suppression of the locally observable Temporal Shear/source-charge sector reconciles local tests with cosmological dynamics. Chameleon, Vainshtein, Galileon, DBI, and symmetron mechanisms are treated as candidate microscopic completions, not as the defining ontology of TEP. Screening manifests as a continuous spatial and covariance structure of the scalar time field (Temporal Topology) governed by the temporal potential field and its gradient (Temporal Shear), suppressing geometric deviations in screened regimes while leaving cosmology accessible to dynamics.

These axioms encode Einstein's local invariance as a theorem and extend it: c is exactly invariant for every tangent space of $\tilde{g}_{\mu\nu}$, but global synchronization and one-way timing depend on the dynamical field ϕ .

The scalar time field ϕ is defined on the spacetime manifold of Axiom A1 and is present at every event. The ambient cosmological value $\phi_\infty = 0$ is a boundary condition, not an absence of the field — and a convention fixed at the present epoch, not an eternal pinning: past ambient values are set by the solved landscape and remain within the fixed-time spatial contrast $|\delta u| \lesssim 10^{-3} - 10^{-2}$ (Section 8), since no source term drives the unsourced void sector secularly. What distinguishes dense from dilute environments is not the presence or absence of ϕ but the matter trace $T^{(\text{m})}$ and the environmental state vector $\mathcal{E}$ (ambient density, compactness, gradients, boundary geometry). The term "vacuum" is retained in its standard field-theory sense — the $T^{(\text{m})} = 0$ limit of the matter sector — and does not denote a region devoid of the temporal field.

Environmental screening $\mathcal{S}_\Sigma(\mathcal{E})$ suppresses the conformal gradient $\Sigma_\mu = \nabla_\mu \ln A$. In TEP, this spatial gradient—measuring how clock tick-rates slope from one point to another—is formally named the Temporal Shear. It governs the geometric refraction of matter: when the slope is steep, matter geodesics bend; when it is flat ($\Sigma_\mu \rightarrow 0$), matter follows standard General Relativity paths. The Temporal Shear is suppressed via temporal-topology pinning: the environmental-state operator $\mathcal{S}_\Sigma(\mathcal{E})$ acts on the solved environmental state — set by source density, compactness, boundary geometry, and ambient field — and its derived shear branch pins the incremental gradient where the ambient time-gradient is steep (in weak-field terms, $g \gg g_t \approx cH_0/2$; Section 7). It does not suppress the disformal sector $B(\phi)$, which is governed by its own field-space envelope (Section 2.2). The two are distinct mechanisms operating on distinct sectors of the disformal map. The amplitude/shear split ($\mathcal{S}_\Sigma \rightarrow 0$, $\mathcal{S}_A \sim 1$) suppresses the spatial gradient while preserving the field value: $A(\phi)$ continues to vary inside screened matter, which is why clocks run slower in deeper wells. What is pinned is the gradient, not the field amplitude. Theorem 2 (Section 6) further establishes that a static conformal

gradient produces no directional photon-propagation asymmetry; direction-dependent null propagation requires the disformal sector, time-dependent geometry, or another non-exact transport contribution.

Sector mapping

Sector	Physical effect	Coupling	Key bound
Temporal lapse & ruler factors ($A_{\text{loc}}, A_{\text{sp}}$)	Clock rates, proper-time rescaling, cosmological ruler drift (A_{sp}), and reciprocity-even temporal-lapse optical refraction when $A_{\text{loc}} \neq A_{\text{sp}}$ on unstretched γ_{ij}	Universal (β_A)	Cassini PPN- γ (via screened S_Σ source charge), redshift tests; $c_{\text{GW}} = c_\gamma$ via shared $\square_{\text{TEP}}$ (§2.2)
Transverse disformal $B(\phi)$	GW–EM cone splits, direction-dependent propagation, and closed-loop holonomy	Small, environment-dependent	GW170817: $ c_\gamma - c_g /c \lesssim \text{few} \times 10^{-15}$
Temporal Topology	Spatial/covariance structure of $\ln A(\phi)$	Field configuration + gradient suppression	Clock/covariance correlation length λ_T

In the isotropic shorthand ($A_{\text{loc}} = A_{\text{sp}} = A$), the conformal factor rescales clock rates and spatial rulers equally and cancels out of null trajectories; in the resolved preferred-foliation metric ($A_{\text{loc}} \neq A_{\text{sp}}$ on unstretched γ_{ij}), $A_{\text{loc}}(u_{\text{grav}})$ also generates reciprocity-even temporal-lapse refraction while preserving $c_{\text{GW}} = c_\gamma$ on the shared wave operator $\square_{\text{TEP}}$ (§2.2). The transverse disformal sector $B(\phi)$ governs differential GW–EM cone tilts and closed-loop synchronization holonomy. GW170817 directly bounds differential GW–EM cone splits governed by B ; it does not directly constrain common-mode clock-rate structure or shared-cone temporal-lapse refraction, although local gradients and source charges remain constrained by PPN, gravitational-redshift, clock-comparison, and equivalence-principle tests.

2.1 Relation to Other Modified Gravity Frameworks

The TEP framework can be situated within the broader landscape of modified gravity and scalar-tensor theories. To clarify its unique features, a comparative analysis is provided:

Table 1: Comparison with Other Scalar-Tensor Frameworks

Theory/Framework	Key Fields	Matter Coupling	$c_g = c_\gamma?$	Key Observable Signature
TEP (This work)	$g_{\mu\nu}, \phi$	Universal to $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu} + B\partial_\mu\phi\partial_\nu\phi$	Equal in conformal/common-mode limit; differential deviations possible through B and constrained by same-path EM–GW timing	Synchronization Holonomy H_{resid}
Horndeski	$g_{\mu\nu}, \phi$	Minimal to $g_{\mu\nu}$	Yes, after GW170817 constraints	Modified growth, ISW
DHOST	$g_{\mu\nu}, \phi$	Minimal to $g_{\mu\nu}$	Yes, for specific degenerate classes	Modified growth, screening
TeVēS	$g_{\mu\nu}, A_\mu, \phi$	To a combined metric	No	MOND phenomenology, lensing
SMEFT	SM fields	Lorentz-violating operators	Model-dependent	Anisotropic propagation, CPT violation

The multi-messenger constraint from GW170817 constrains the integrated EM–GW differential disformal contribution along observed late-time astrophysical paths. It does not require the disformal sector to vanish identically in all regimes. In the conformal limit, common-mode path effects cancel in EM–GW timing; residual B -sector structure remains testable through multipath delays, closed-loop holonomy, and topological or interferometric regimes. The model, with a universal conformal coupling $A(\phi)$ and a disformal term $B(\phi)$, automatically satisfies $c_g = c_\gamma$ in the conformal limit ($B = 0$). A non-zero $B(\phi)$ introduces a calculable deviation $c_\gamma \neq c_g$ constrained by future multi-messenger observations.

Conceptually, TEP differs from many scalar-tensor theories by its foundational principle: the universal coupling of matter to a single metric $\tilde{g}_{\mu\nu}$. This is philosophically closer to Bekenstein's TeVeS theory, which also introduced a separate matter metric, but the framework is more minimal, using only a scalar, and makes a distinctive operational prediction in the form of the synchronization holonomy.

2.2 Minimal covariant action

The displayed low-curvature action below represents the leading sector of the master TEP Effective Field Theory. The strong-curvature completion includes higher-order curvature operators (such as the scalar-Gauss-Bonnet coupling $\alpha_{\text{GB}} f(\phi) \mathcal{G}$) which are negligible in the weak-field and cosmological regimes studied here, but become active in the strong-field regime to supply real backreaction (as detailed in TEP-BH, Paper 28). The unified action, including the strong-curvature sector, is

$$S = S_{\text{grav}}[g_{\mu\nu}, \phi] + \int d^4x \sqrt{-g} [P(X, \phi) + \alpha_{\text{GB}} f(\phi) \mathcal{G}] + S_m[\psi_i, \tilde{g}_{\mu\nu}], \quad (2)$$

with the canonical causal (matter) metric

$$\tilde{g}_{\mu\nu} = A^2(\phi) g_{\mu\nu} + B(\phi) \nabla_\mu \phi \nabla_\nu \phi. \quad (3)$$

Decomposed along the unit cosmic temporal flow $U_\mu \equiv -\nabla_\mu \bar{\phi} / \sqrt{2\bar{X}}$ ($g^{\mu\nu} U_\mu U_\nu = -1$, orthogonal spatial projector $\Pi_{\mu\nu} = g_{\mu\nu} + U_\mu U_\nu$, with stationary baryon-sourced temporal-depth perturbation $u_{\text{grav}}(\mathbf{x})$, local lapse factor $A_{\text{loc}}(u_{\text{grav}}) = \exp(\beta_A u_{\text{grav}}) = \exp(-u_{\text{grav}}(\mathbf{x}))$, and matter-frame spatial ruler factor $A_{\text{sp}}(u_{\text{drift}}) = \exp(\beta_A u_{\text{drift}}) = \exp(-u_{\text{drift}}(t, \mathbf{x}))$ with $\dot{u}_{\text{drift}} = -H_{\text{drift}} < 0$), the longitudinal projection along $U_\mu U_\nu = \nabla_\mu \bar{\phi} \nabla_\nu \bar{\phi} / (2\bar{X})$ separates the stationary gravitational/scalar ADM lapse $N_{\text{TEP}}(\mathbf{x}) = A_{\text{loc}}(u_{\text{grav}}(\mathbf{x})) N_{\text{GR}}(\mathbf{x})$ from the matter-frame ruler-drift factor $A_{\text{sp}}(t, \mathbf{x})$ on static gravitational 3-space $\gamma_{ij}(\mathbf{x})$. Substituting $\Pi_{\mu\nu} = g_{\mu\nu} + U_\mu U_\nu$ exhibits this preferred-foliation realization explicitly as an exact member of the covariant conformal-disformal class with longitudinal disformal weight $B_{\parallel} \equiv (A_{\text{sp}}^2(u_{\text{drift}}) - A_{\text{loc}}^2(u_{\text{grav}})) / (2\bar{X})$ along $\nabla_\mu \bar{\phi} \nabla_\nu \bar{\phi}$ and transverse spatial disformal weight $B(\phi)$:

$$\begin{aligned} \tilde{g}_{\mu\nu} &= -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x})) U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x})) \Pi_{\mu\nu} + B(\phi) \Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi \\ &= A_{\text{sp}}^2(u_{\text{drift}}) g_{\mu\nu} + \frac{A_{\text{sp}}^2(u_{\text{drift}}) - A_{\text{loc}}^2(u_{\text{grav}})}{2\bar{X}} \nabla_\mu \bar{\phi} \nabla_\nu \bar{\phi} + B(\phi) \Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi, \end{aligned} \quad (4)$$

with $(3+1)$ ADM line element $d\tilde{s}^2 = -N_{\text{TEP}}^2(\mathbf{x}) c^2 dt^2 + A_{\text{sp}}^2(t, \mathbf{x}) \gamma_{ij}(\mathbf{x}) dx^i dx^j$ at $B=0$ ($\sqrt{-\tilde{g}} = A_{\text{loc}}(u_{\text{grav}}) A_{\text{sp}}^3(u_{\text{drift}}) \sqrt{-g}$; the projected spatial disformal term contributes an additional factor $\sqrt{1 + B(\Pi \nabla \phi)^2 / A_{\text{sp}}^2}$). This single covariant metric governs both cosmological and astrophysical regimes across the entire corpus without ambiguity. On the homogeneous intergalactic background ($u_{\text{grav}} = 0$, $N_{\text{TEP}} = 1$, $\Pi_\mu^\alpha \nabla_\alpha \phi = 0$, where u_{drift} rolls from $\ln(1+z) > 0$ at emission to 0 today at rate $\dot{u}_{\text{drift}} = -H_{\text{drift}} < 0$), $A_{\text{sp}}(t) = \exp(\beta_A u_{\text{drift}}(t)) = \exp(-u_{\text{drift}}(t)) = (1+z)^{-1}$ measures how many matter-frame Bohr radii ($\ell_{\text{unit}}^{\text{coord}} = \ell_0 / A_{\text{sp}}(t) = \exp(+u_{\text{drift}}) \ell_0$ in static gravitational coordinates — a conformal recalibration of matter-frame units across epoch, not a mechanical contraction of atoms) fit across a fixed static coordinate interval dx ($d\tilde{\ell} = A_{\text{sp}}(t) dx$), producing the cosmological redshift $1+z = A_{\text{sp}}(t_o) / A_{\text{sp}}(t_e) = A_o / A_e$, source area distance $D_A = A_e r$, and the standard-siren relation $\Xi(z) = d_L^{\text{GW}} / d_L^{\text{EM}} = 1/(1+z)$ (Section 8). For inhomogeneous spatial structures $u_{\text{grav}}(\mathbf{x}) = \delta\phi(\mathbf{x}) / M_{\text{Pl}}$ at a fixed cosmic epoch ($A_{\text{sp}}(t_0) = 1$), it reduces identically to the unstretched-space temporal metric $\tilde{g}_{\mu\nu} = g_{\mu\nu} - (A_{\text{loc}}^2(u_{\text{grav}}) - 1) U_\mu U_\nu + B(\phi) \Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$, where spatial rulers $\tilde{\gamma}_{ij} = \gamma_{ij} = (1 - 2\Phi_N / c^2) \delta_{ij}$ remain unstretched while the $(3+1)$ ADM spacetime lapse rescales as $N_{\text{TEP}}(\mathbf{x}) = A_{\text{loc}}(u_{\text{grav}}(\mathbf{x})) N_{\text{GR}}(\mathbf{x})$ ($\sqrt{-\tilde{g}} = A_{\text{loc}}(u_{\text{grav}}) \sqrt{-g}$).

Preferred-foliation (khronon) EFT realization and shared wave operator

Because the scalar time field possesses an everywhere-timelike cosmic gradient ($X \equiv -\frac{1}{2} g^{\mu\nu} \nabla_\mu \phi \nabla_\nu \phi > 0$), the unit four-velocity $U_\mu \equiv -\nabla_\mu \phi / \sqrt{2X}$ ($g^{\mu\nu} U_\mu U_\nu = -1$) spontaneously selects a preferred cosmological temporal foliation. This places the gravitational sector naturally within the spatially covariant ADM, khronon (Blas, Pujolàs & Sibiryakov 2010), and degenerate higher-order scalar-tensor (DHOST) effective field theory framework. Crucially, this global foliation selection does not violate local Lorentz invariance in the matter sector: because all non-gravitational fields couple universally to the single effective metric $\tilde{g}_{\mu\nu}$ (Axiom A2), boost invariance is exact in every local $\tilde{g}_{\mu\nu}$ freely falling frame, while the cosmic rest frame U_μ governs the separation between temporal lapse depth and spatial ruler drift on macroscopic scales. On the U_μ foliation over static gravitational space $\gamma_{ij}(\mathbf{x})$ with strictly constant M_{Pl} , the gravitational sector is the spatially covariant ADM/DHOST action

$$\begin{aligned}
S_{\text{grav}} &= \frac{M_{\text{Pl}}^2}{2} \int d^3x dt \sqrt{\gamma} N_{\text{GR}} \left[R_{\text{scalar}}^{(3)}(\gamma) + A_{\text{sp}}^{-1}(t, \mathbf{x}) R_{\text{TT}}^{(3)}(\gamma) + \frac{A_{\text{sp}}(t, \mathbf{x})}{A_{\text{loc}}^2(u_{\text{grav}})} (K_{ij} K^{ij} - K^2) \right] \\
&= \frac{M_{\text{Pl}}^2}{2} \int d^3x dt \sqrt{\gamma} N_{\text{GR}} \left[A_{\text{sp}}^{-1}(t, \mathbf{x}) R^{(3)}(\gamma) + 2(A_{\text{sp}}^{-1}(t, \mathbf{x}) - 1) \gamma^{ij} D_i \ln N_{\text{GR}} D_j \ln N_{\text{GR}} + \tilde{K}_{ij} \tilde{K}^{ij} - \tilde{K}^2 \right]
\end{aligned}$$

with physical extrinsic curvature $\tilde{K}_{ij} \equiv A_{\text{sp}}^{1/2}(t, \mathbf{x}) (2N_{\text{TEP}} c)^{-1} \partial_t \gamma_{ij} = A_{\text{sp}}^{1/2}(t, \mathbf{x}) A_{\text{loc}}(u_{\text{grav}})^{-1} K_{ij}$ (Appendix E, R19; `step_80_shared_lapse_action_derivation.py`). Here $R_{\text{scalar}}^{(3)}(\gamma)$ and $R_{\text{TT}}^{(3)}(\gamma)$ are defined explicitly as the quadratic scalar–vector–tensor (SVT) curvature pieces of the spatial 3-metric $\gamma_{ij} = (1 - 2\Phi_N/c^2)\delta_{ij} + h_{ij}^{\text{TT}}$ around the static background: expanding $\sqrt{\gamma} N_{\text{GR}} R^{(3)}(\gamma)$ to second order in perturbations (with $N_{\text{GR}} = 1 + \Phi_N/c^2$ and total spatial divergences integrated by parts) yields $\sqrt{\gamma} N_{\text{GR}} R_{\text{scalar}}^{(3)}(\gamma) = -2(\nabla\Phi_N/c^2)^2$ (corresponding to $R_{\text{scalar}}^{(3)} = (4/c^2)\nabla^2\Phi_N - (2/c^4)(\nabla\Phi_N)^2$) and $\sqrt{\gamma} N_{\text{GR}} R_{\text{TT}}^{(3)}(\gamma) = -\frac{1}{4}\gamma^{kl}\partial_k h_{ij}^{\text{TT}}\partial_l h_{ij}^{\text{TT}}$. As shown by the second equality above, this quadratic SVT effective action admits a strictly local, covariant khronon/preferred-foliation representation (Blas, Pujolàs & Sibiryakov 2010): because the unit timelike gradient $U_\mu \equiv -\nabla_\mu \phi / \sqrt{2X}$ defines the local spatial acceleration 3-vector $a_i \equiv U^\nu \nabla_\nu U_i = D_i \ln N_{\text{GR}} = \partial_i \Phi_N / c^2$, the longitudinal scalar potential piece is generated locally by $a_i a^i = \gamma^{ij} D_i \ln N_{\text{GR}} D_j \ln N_{\text{GR}} = (\nabla\Phi_N/c^2)^2$, reproducing $R_{\text{scalar}}^{(3)}(\gamma) + A_{\text{sp}}^{-1} R_{\text{TT}}^{(3)}(\gamma)$ identically at quadratic order without solving a non-local Poisson inverse Laplacian.

Because the longitudinal elliptic spatial 3-curvature $R_{\text{scalar}}^{(3)}(\gamma)$ is weighted by strictly constant $M_{\text{Pl}}^2 N_{\text{GR}}$ rather than N_{TEP} (unlike a trivial Jordan-frame action $\int \sqrt{-\tilde{g}} R[\tilde{g}]$, which would eliminate the scalar fifth force), $\delta S_{\text{grav}} / \delta u_{\text{grav}} \equiv 0$ and $\delta S_{\text{grav}} / \delta A_{\text{sp}} \equiv 0$ in the quasistatic limit ($K_{ij} \rightarrow 0$, $h_{ij}^{\text{TT}} = 0$), so varying $S_{\text{grav}} + S_\phi + S_m$ preserves the Newtonian Poisson equation $\nabla^2 \Phi_N = \rho_*/(2M_{\text{Pl}}^2)$ and the scalar source equation $\nabla \cdot (P_{,X} \nabla \phi) = V_{,\phi} + \rho_* A_{,\phi}$ identically. Simultaneously, varying S_{grav} with respect to transverse-traceless perturbations h_{ij}^{TT} of γ_{ij} and varying the Maxwell action $S_{\text{EM}}[\tilde{g}] = -\frac{1}{4} \int d^4x \sqrt{-\tilde{g}} \tilde{g}^{\mu\alpha} \tilde{g}^{\nu\beta} F_{\mu\nu} F_{\alpha\beta}$ with respect to the transverse vector potential A_i^T yields the quadratic wave actions

$$\begin{aligned}
S_{\text{TT}}^{(2)} &= \frac{M_{\text{Pl}}^2}{8} \int d^3x dt \sqrt{\gamma} N_{\text{GR}} A_{\text{sp}}(t, \mathbf{x}) \left[\frac{(\partial_t h_{ij}^{\text{TT}})^2}{N_{\text{TEP}}^2(\mathbf{x}) c^2} - \frac{1}{A_{\text{sp}}^2(t, \mathbf{x})} \gamma^{kl} \partial_k h_{ij}^{\text{TT}} \partial_l h_{ij}^{\text{TT}} \right], \\
S_{\text{EM}}^{(2)} &= \frac{1}{2} \int d^3x dt \sqrt{\gamma} N_{\text{TEP}} A_{\text{sp}}(t, \mathbf{x}) \left[\frac{(\partial_t A_i^T)^2}{N_{\text{TEP}}^2(\mathbf{x}) c^2} - \frac{1}{A_{\text{sp}}^2(t, \mathbf{x})} \gamma^{kl} \partial_k A_i^T \partial_l A_i^T \right],
\end{aligned} \tag{6}$$

whose Euler–Lagrange equations share the identical principal wave operator $\square_{\text{TEP}} \equiv -(N_{\text{TEP}} c)^{-2} \partial_t^2 + A_{\text{sp}}^{-2}(t, \mathbf{x}) \gamma^{kl} \partial_k \partial_l$, coordinate phase speed $c_{\text{GW}}(t, \mathbf{x}) = c_\gamma(t, \mathbf{x}) = c N_{\text{TEP}}(\mathbf{x}) A_{\text{sp}}^{-1}(t, \mathbf{x}) \gamma_{ll}^{-1/2}$ at every event $(t, \mathbf{x})$ ($\Delta t_{\gamma\text{-GW}} \equiv 0$ identically along all cosmological and local paths, including GW170817), and shared refractive index $n(x) \simeq 1 - 2\Phi_N(x)/c^2 - \beta_A u_{\text{grav}}(x)$ at fixed epoch ($A_{\text{sp}} = 1$) and $B = 0$. Crucially, while photons and gravitons share the null cone $d\eta = dt/A_{\text{sp}}(t, \mathbf{x})$, the WKB geometric-mean amplitude weight of $S_{\text{TT}}^{(2)}$ on static gravitational space ($\sqrt{\gamma} = 1$) is $\sqrt{A_{\text{sp}}^{+1} \cdot A_{\text{sp}}^{-1}} \equiv 1$ (constant, unlike expanding FLRW where $\sqrt{\gamma} = a^3(\eta)$ produces an $a^2(\eta)$ WKB weight and $2\mathcal{H}\partial_\eta h_{ij}^{\text{TT}}$ Hubble friction), so h_{ij}^{TT} decays geometrically as $1/r$ on static space and preserves the diffeomorphism-invariant standard-siren discriminator $\Xi(z) = d_L^{\text{GW}}/d_L^{\text{EM}} = 1/(1+z) \neq 1$ (Section 8, Step 80), while the non-relativistic point-particle action $S_{\text{pp}} = -mc \int \sqrt{-\tilde{g}_{\mu\nu}} dx^\mu dx^\nu$ yields $L_{\text{pp}} \simeq -mc^2(1 + \Phi_N/c^2 + \beta_A u_{\text{grav}} - \frac{1}{2} v^2/c^2)$ and $\mathbf{a} = -\nabla\Phi_N - c^2 \beta_A \nabla u_{\text{grav}}$.

The adopted kinetic realization is the two-branch sector $P(X, \phi) = -V(\phi) + \frac{2k}{3\Lambda_X^2} X|X|^{1/2} + X|X|/\Lambda_X^4$, with $X = -\frac{1}{2}(\nabla\phi)^2$, $\xi = |X|/\Lambda_X^4$, and $k = 4\sqrt{2} g_t/a_0 \simeq 16$ derived from the adopted acceleration constant, as developed below. The sector carries no canonical term: every completion restoring a linear small- ξ limit reverts to a Keplerian tail and is rejected by the flat-asymptote constraint, while all quoted Solar-System benchmarks sit on the quadratic-dominated branch $\xi \gg \xi_* = (k/2)^2 \simeq 64$ where the earlier $X|X|/\Lambda_X^4$ calculations carry over unchanged. The strong-curvature term is evaluated in the black-hole completion (Paper 28); the weak-field calculations neglect that term while retaining the nonlinear kinetic response where required. Canonical-only and alternative-kinetic calculations are identified as benchmarks of their stated branches.

Canonical microscopic structure

The universal conformal coupling, the conformal–disformal matter metric architecture, and the observable Temporal-Topology response structure are fixed. The framework cleanly divides responsibilities: the two-body operator $\mathcal{S}_{\text{eff}}$ governs pairwise Temporal Shear recovery, while the scalar self-interaction $V(\phi)$ must remain flat/shallow across the matter-hosting domain to satisfy cosmological background constraints. The candidate master potential of Section 8 is a single smooth (C^∞) function whose essential singularity supplies the locally flat potential floor required by the temporal-well roll (Appendix E, R3). The items below specify the canonical microscopic structure.

Conformal coupling. The conformal factor is fixed universally as

$$A(\phi) = \exp\left(\frac{\beta_A \phi}{M_{\text{Pl}}}\right), \quad \beta_A = -1.0, \quad (7)$$

so that the dimensionless coupling $d \ln A / d\phi = \beta_A = -1$ is frozen (equivalently $\alpha_0 = \sqrt{2} \beta_A$ in DEF normalization), where $\varphi \equiv \phi / M_{\text{Pl}}$ is the dimensionless field variable. The weak-field Solar-System safety is not a second parameter $\beta \approx -0.013$ but the screened source charge $S_\Sigma^{(\odot)} \alpha_0$: under the unstretched-space temporal metric $(\tilde{g}_{00} = -(1 + 2\Phi_{\text{dyn}}/c^2))$ with $\Phi_{\text{dyn}} = \Phi_N + c^2 \beta_A u = (1 + 2\beta_A^2 S_\Sigma^{(\odot)}) \Phi_N$ and unstretched spatial curvature $\tilde{g}_{ij} = (1 - 2\Phi_N/c^2) \delta_{ij}$, the PPN gravitational slip is linear in the solar charge fraction, providing the strict, sign-definite prediction $\gamma_{\text{PPN}} - 1 = -2\beta_A^2 S_\Sigma^{(\odot)} / (1 + 2\beta_A^2 S_\Sigma^{(\odot)}) < 0$ (or $-4\beta_A^2 S_\Sigma^{(\odot)} / (1 + 2\beta_A^2 S_\Sigma^{(\odot)})$ on the isotropic-conformal benchmark), constrained by Cassini to $|\gamma_{\text{PPN}} - 1| < 2.3 \times 10^{-5}$, fixing $S_\Sigma^{(\odot)} \lesssim 1.15 \times 10^{-5}$ (5.8×10^{-6} on the isotropic benchmark; on the selected two-branch kinetic sector at solar conjunction $r = 1.6 R_\odot$, $y_{\text{tb}} = 2.16 \times 10^{-8}$ gives $|\gamma_{\text{PPN}} - 1| \simeq 4.32 \times 10^{-8}$, more than $500\times$ below the Cassini bound; Step 80). The terrestrial amplitude factor $S_A^{(\oplus)}$ characterizes Earth's static conformal-depth response; time-dependent GNSS clock covariance is described by C_A together with the perturbation and measurement transfer of the same solved configuration. The Solar-System source-charge factor $S_\Sigma^{(\odot)}$ is a different projection and need not equal $S_A^{(\oplus)}$.

Sign convention for ϕ (corpus-wide). The scalar field is defined such that $\phi > 0$ in the vicinity of a mass concentration, with the ambient cosmological value taken as the zero point by convention, $\phi_\infty = 0$. Combined with the frozen coupling $\beta_A = -1$, this fixes every downstream sign in the framework:

- $A(\phi) = \exp(\beta_A \varphi) < 1$ near a mass, so the conformal factor is *suppressed* in a potential well.
- Since matter clocks tick at $d\tau/dt \simeq A(\phi)$, clocks run slower in deeper wells. This reproduces the sign of the ordinary gravitational redshift and is therefore the convention consistent with general relativity in the screened limit.
- The Temporal Shear $\Sigma_\mu \equiv \nabla_\mu \ln A = \beta_A \nabla_\mu \varphi$ points *outward* from a mass (since $\beta_A < 0$ and $\nabla_\mu \varphi$ points inward).
- Consequently $\beta_A \phi < 0$ near a mass, and $\Delta \ln A < 0$ relative to the ambient environment.

The opposite choice ($\phi < 0$ near a mass, giving $A > 1$ and clocks running *faster* in wells) is inconsistent with the measured sign of gravitational redshift and is not used anywhere in this corpus. Any paper reporting a conformal-sector sign should be checked against this convention before its result is compared with another paper's. Where a manuscript quotes $|\beta_A|$ or an unsigned effective coupling, that is a magnitude and carries no sign information. Under the preferred-foliation decomposition $\varphi(t, \mathbf{x}) \equiv \phi(t, \mathbf{x}) / M_{\text{Pl}} = u_{\text{drift}}(t, \mathbf{x}) + u_{\text{grav}}(\mathbf{x})$, the background drift u_{drift} and the local gravitational perturbation u_{grav} superimpose linearly with the single universal coupling $\beta_A = -1$ and zero sign contradiction: at cosmic lookback redshift $z > 0$, $u_{\text{drift}}(t_e) = \ln(1 + z) > 0$ rolls to $u_{\text{drift}}(t_o) = 0$ today ($\dot{u}_{\text{drift}} = -H_{\text{drift}} < 0$), giving $A_{\text{sp}}(u_{\text{drift}}) = \exp(\beta_A u_{\text{drift}}) = \exp(-u_{\text{drift}}) = (1 + z)^{-1} < 1$ on $\Pi_{\mu\nu}$, while in a local gravitational potential well ($\Phi_N < 0$), $u_{\text{grav}}(\mathbf{x}) = 2\beta_A S_\Sigma \Phi_N / c^2 > 0$ gives $A_{\text{loc}}(u_{\text{grav}}) = \exp(\beta_A u_{\text{grav}}) = \exp(-u_{\text{grav}}) < 1$ on $U_\mu U_\nu$. Both sectors therefore obey the identical exponential suppression law $A(u) = \exp(-u) < 1$ for $u > 0$ and factorize cleanly in moving-endpoint and local clock observables without algebraic cross-contamination.

Bidirectionality and the weak-field normalization ledger. The prohibition above concerns the sign of A in potential wells. The conformal factor nevertheless deviates symmetrically relative to the ambient medium ($A = 1$): $A < 1$ in overdensities (clocks tick slower) and $A > 1$ in underdensities (clocks tick faster). Here Φ_N denotes the Einstein-frame Newtonian metric potential, fixed by $\nabla^2 \Phi_N = \rho_*/(2M_{\text{Pl}}^2)$ and $\Phi_N = -GM/(c^2 r) < 0$ outside an isolated positive mass. In the canonical quasistatic limit, $\nabla^2 \delta\phi = \beta_A \rho_*/M_{\text{Pl}}$ therefore gives

$$\frac{\delta\phi}{M_{\text{Pl}}} = 2\beta_A \Phi_N, \quad \ln \frac{A}{A_\infty} = 2\beta_A^2 \Phi_N. \quad (8)$$

For a static scalar, the matter-frame lapse is $\tilde{N} = AN$. With $N/N_\infty = e^{\Phi_N} + O(\Phi_N^2)$, the bare unscreened branch obeys

$$\frac{\tilde{N}}{N_\infty} = \exp[(1 + 2\beta_A^2) \Phi_N] + O(\Phi_N^2) = e^{3\Phi_N} + O(\Phi_N^2), \quad \frac{G_{\text{eff}}}{G} = 1 + 2\beta_A^2 = 3, \quad (9)$$

where the final equalities use the frozen value $\beta_A = -1$. Thus Φ_N is not the potential inferred from unscreened matter motion: the latter is $3\Phi_N$ at leading order. This factor is precisely why environmental suppression is required for every macroscopic source, not only the Sun. For a screened exterior source, the observable lapse gradient is instead

$$\nabla \ln \tilde{N} = [1 + 2\beta_A^2 S_\Sigma(\mathcal{E})] \nabla \Phi_N, \quad (10)$$

so $S_\Sigma \rightarrow 0$ recovers the GR lapse gradient and $G_{\text{eff}} \rightarrow G$. A common ambient value of A cancels from local clock comparisons; it must not be confused with the exterior source-charge gradient governed by S_Σ , while finite clock-amplitude offsets remain governed separately by S_A . The coefficient ledger is derived independently of fitted data (Appendix E, R9). Along an extended line of sight through the cosmic web, exact conformal excursions spatially average out to recover the smooth cosmological background. However, the non-exact covariance $\mathcal{C}_T$ (Paper 26) retains a cumulative, macroscopic residual that resists spatial averaging. This distinction between exact conformal averaging and non-exact residual survival is the physical content of the $\Sigma_{\parallel} + \mathcal{C}_{T,\parallel}$ decomposition of Paper 26.

Disformal coupling. The matter metric contains a disformal coupling function $B(\phi)$. Observable disformal effects depend on the complete combination $B(\phi)\nabla_\mu\phi\nabla_\nu\phi$, rather than on $B(\phi)$ alone. Paper 28 employs the field-space envelope

$$B(\phi) = B_0 \frac{\varphi^2}{1 + \varphi^2} \exp\left(-\frac{\varphi^4}{2\sigma_B^4}\right), \quad \varphi \equiv \phi/M_{\text{Pl}}, \quad (11)$$

as a prescribed strong-field realization. At weak-field values ($\varphi \sim 10^{-10}$), the exponential damping factor is unity to extremely high precision and $\varphi^2/(1 + \varphi^2) \simeq \varphi^2$, so $B(\phi) \simeq B_0\varphi^2$ throughout terrestrial and typical astrophysical environments. Its rapid large- $|\varphi|$ damping provides additional strong-field suppression of the disformal contribution, enforcing conformal dominance and protecting the Lorentzian matter-metric branch when scalar gradients become extreme. This field-space envelope is not identified with ordinary environmental Temporal-Topology screening, which arises primarily through the environment-dependent scalar configuration and its active gradient. The unique corpus-wide microscopic form and normalization of $B(\phi)$ therefore remain part of the action-closure problem. In the dimensionful Jakarta field convention, B_0 carries mass dimension -4 so that $B(\phi)\nabla_\mu\phi\nabla_\nu\phi$ is dimensionless; numerical normalizations employed in Paper 28's geometrized, dimensionless-field strong-field construction are therefore not imported directly into the weak-field theory. GW170817 constrains the path-integral combination $B(\phi)(\partial\phi)^2$ along observed late-time astrophysical paths; it does not require $B \equiv 0$ in every regime. The theory field ϕ remains dimensionful (mass dimension 1) throughout, consistent with the canonical kinetic term $-\frac{1}{2}(\nabla\phi)^2$ and the conformal factor $A = \exp(\beta_A\phi/M_{\text{Pl}})$; φ is introduced only as a shape variable for B . The strong-field regime in which this envelope is exercised by Paper 28 lies beyond the small- B EFT domain in which the invertibility and signature conditions of Section 4 are established; those applications are conditional on the completed nonlinear realization.

Temporal-Topology saturation sector. Environmental suppression in TEP is defined by the continuous response of the Temporal Topology rather than by a discrete density threshold or thin-shell boundary. Writing $\Theta \equiv \ln A(\phi)$ and $\Sigma_\mu \equiv \nabla_\mu\Theta$, the conformal-amplitude response S_A and the Temporal-Shear/source-charge response S_Σ are distinct observable projections of the same environment-dependent scalar configuration. The macroscopic scale

$$\rho_T \simeq 20 \text{ g cm}^{-3} \quad (12)$$

denotes the empirically calibrated Temporal-Topology saturation/reference scale. It is not a universal microscopic density cutoff and does not define a binary screened/unscreened transition. In the weak-field, canonical $K \rightarrow 1$, $B \rightarrow 0$, quasistatic limit, a particular microscopic completion must satisfy the scalar field equation $\nabla^2\phi = V_{,\phi} + \mathcal{Q}_m$, with the matter-source convention defined consistently with the action of Section 2.2. Defining the conserved Einstein-frame density $\rho_* = A^3\tilde{\rho}$, the field equation reads

$$\nabla^2\phi = V_{,\phi} + \rho_* A_{,\phi}. \quad (13)$$

In regions where a particular completion admits an adiabatic density-dependent equilibrium, this may reduce to a local balance of the form $V_{,\phi} + \rho_* A_{,\phi} \simeq 0$. Such an effective minimum is one possible local realization of Temporal-Topology saturation; it is not the defining screening ontology of TEP. Chameleon, Vainshtein, Galileon, DBI, symmetron, and related mechanisms therefore remain candidate microscopic realizations rather than definitions of the framework. The observable spatial gradient suppression is natively handled by the two-body kinetic operator, leaving the potential $V(\phi)$ free to satisfy the shallow background conditions required by cosmology.

Screening operators. Two projections of the solved nonlinear field configuration are needed. The field-amplitude (clock) screening S_A measures the suppression of the conformal factor excursion relative to its unscreened cosmological baseline (Paper 26; Appendix

E, R7):

$$S_A(\mathcal{E}) \equiv \frac{(A(\phi(\mathbf{r})) - 1)_{\text{local}}}{(A(\phi) - 1)_{\text{unscreened}}}, \quad (14)$$

The source-charge (shear) screening S_Σ measures the suppression of the local scalar response relative to the unscreened expectation — in the kinetic realization adopted here, the ratio of the solved nonlinear gradient to its linear extrapolation, equivalently the inverse stiffness for an incremental source on an ambient kinetic background:

$$S_\Sigma(\mathcal{E}) \equiv \frac{|\nabla\phi|_{\text{nonlinear}}}{|\nabla\phi|_{\text{linear}}} \simeq \frac{Q_{\text{eff}}}{Q_0} = \frac{\alpha_{\text{eff}}}{\alpha_0}, \quad (15)$$

where $\phi(\mathbf{r})$ is the solved static profile for the given source geometry, density, compactness, and boundary conditions. The effective-charge form Q_{eff}/Q_0 is the far-field matching shorthand: in the $P(X, \phi)$ realization the Gauss flux $\oint P_{,X} \nabla\phi \cdot d\mathbf{A}$ is conserved through the nonlinear shell (the source charge is not destroyed), and the suppression an observer infers is the local field gradient, which the constant-charge PPN parametrization then records as a reduced effective exterior coupling. Both projections are observable responses of the same physical nonlinear field configuration rather than independent domain-by-domain couplings. Their macroscopic environmental response is supplied by the corpus-wide $S_\Sigma(\mathcal{E})$ construction; the kinetic realization adopted in this paper is specified at the end of this section, with alternative $K(X)$ forms standing as candidate realizations to be tested against its derived predictions. S_A characterizes the static conformal-depth response; S_Σ characterizes the specified gradient/source response. Time-dependent clock covariance is carried by C_A together with the perturbation and measurement transfer of the same solved configuration. These responses need not be numerically identical. Appendix E, R17 computes static boundary susceptibilities and finite-exursion responses, not a universal transmission: approximately additive response is a regime-dependent limit, and propagation through the ambient medium must be distinguished from penetration into the body. No independent clock-sector coupling is introduced. In composite observables the assignment is positional at leading order in the test-probe expansion: the probe's perturbation of the host's solved field and the resulting mixed boundary terms are neglected. This assignment is not a decomposition of the scalar action into independent habitat and probe fields; finite-mass binaries require the nonlinear boundary-value problem with both sources present. Within that stated approximation, the assignment is positional: the factor multiplying a host's potential contribution to the environmental field coordinate is the source-side charge suppression, S_Σ evaluated at the habitat density — the ambient-density limit $[1 + (\rho/\rho_{\text{half}})^2]^{-1}$ with $\rho_{\text{half}} \approx 0.5 M_\odot \text{ pc}^{-3}$ (Paper 26) — while the probe's own clock-amplitude response is S_A evaluated at the probe's material density, a per-source factor absorbed into the channel response coefficient (e.g., the Cepheid κ_{Cep} of Papers 11 and 31) rather than into the environmental coordinate. Strong gradient flattening suppresses S_Σ , while S_A depends separately on the local field amplitude relative to its reference environment. The mesoscopic screening law of the companion Paper 25 (in preparation; $S_\Sigma^{\text{meso}} = S_{\text{TEP}} \times S_{\text{TF}} \times S_{\text{boundary}} \times S_{\text{decoherence}}$) is a factorization of S_Σ at intermediate scales.

Radial ODE closure calculation. The static weak-field scalar equation $\nabla^2\phi = V_{,\phi} + \rho_* A_{,\phi}$ is solved numerically for a spherical source with the bidirectional conformal coupling $A(\phi) = \exp(-\phi/M_{\text{Pl}})$, $\beta_A = -1$, using `scipy.integrate.solve_bvp` with core regularity ($\phi'(0) = 0$) and cosmological relaxation ($\phi(r_{\text{max}}) \rightarrow 0$) boundary conditions (Appendix E, R1). The key dimensionless parameter is the unscreened field amplitude $\psi_{\text{uns}} = M/(4\pi M_{\text{Pl}}^2 R)$, which controls the strength of the conformal nonlinearity. Two theoretical baselines are evaluated against the Cassini bound $|\gamma_{\text{PPN}} - 1| < 2.3 \times 10^{-5}$ (requiring $S_\Sigma^{(\odot)} \lesssim 1.15 \times 10^{-5}$ under the unified unstretched-space metric, or 5.8×10^{-6} on the isotropic-conformal benchmark):

(i) $V = 0$ (pure bidirectional conformal screening). The nonlinear source $-(\rho_*/M_{\text{Pl}}) \exp(-\phi/M_{\text{Pl}})$ provides gradient flattening in overdensities ($\phi > 0$, $\exp(-\phi/M_{\text{Pl}}) < 1$, source weakened) and enhancement in underdensities ($\phi < 0$, $\exp(-\phi/M_{\text{Pl}}) > 1$). The screening correction is $O(\psi_{\text{uns}}) \sim 4 \times 10^{-6}$ for the Sun — only a fractional reduction of the effective charge, leaving $S_\Sigma \approx 1$, far above the Cassini requirement $S_\Sigma \lesssim 1.15 \times 10^{-5}$ (5.8×10^{-6} isotropic). The conformal nonlinearity alone is too weak for Solar-System screening.

(ii) Kinetic completion of two-body screening — microscopic realization. The effective Temporal-Topology response is produced by the nonlinear interaction of overlapping scalar-field gradients in the nested environmental landscape. The noncanonical completion selected by the corpus's master-sector admissibility scan (Appendix E, step 54; master-sector ledger, `TEP/closure/`) is the two-branch sector

$$P(X, \phi) = -V(\phi) + \frac{2k}{3\Lambda_X^2} X |X|^{1/2} + \frac{X |X|}{\Lambda_X^4}, \quad X = -\frac{1}{2} (\nabla\phi)^2, \quad (16)$$

whose kinetic response function on the static branch is $P_{,X} = k\sqrt{\xi} + 2\xi$ with $\xi \equiv |X|/\Lambda_X^4$. The selection is a derived result, not an ansatz choice: within the surveyed power-law family $P_{,X} = k\xi^p + 2\xi$ a flat rotation asymptote ($a_\phi \propto 1/r$, the deep-RAR tail) requires $p = 1/2$ uniquely, while every completion restoring a linear small- ξ limit — including the incumbent unit-term form $P_{,X} = 1 + 2\xi$ and the unit-term two-branch variant — reverts to a Keplerian tail and is rejected. The sector therefore carries no canonical term and has no canonical small-gradient limit: $P_{,X} \rightarrow 0$ as $\xi \rightarrow 0$. The stiffness can equal unity at an isolated finite field value without making the kinetic function canonical. The coefficient is fixed by the deep-tail flux law: flux conservation gives $a_\phi^2 = a_{\text{eff}} g_N$ with $a_{\text{eff}} = 4\sqrt{2}|\beta_A|g_t/k$, so the adopted empirical acceleration constant $a_0 \simeq 1.2 \times 10^{-10} \text{ m s}^{-2}$ returns $k = 4\sqrt{2}g_t/a_0 \simeq 16.0$ — a derived coefficient, not a fit. The two terms cross over at $\xi_* = (k/2)^2 \simeq 64$: the Solar-System and strong-field benchmarks of Section 7 all sit at $\xi \sim 10^2\text{--}10^{23} \gg \xi_*$, where the quadratic asymptote governs the largest- ξ results; finite-gradient calculations retain both terms, whose relative contribution is $k/(2\sqrt{\xi})$, while the Galactic ambient ($\xi \sim 0.3\text{--}0.5$), the wide-binary pair region ($\xi \sim 10$), and the void sector ($\xi \sim 10^{-5}$, where $\mathcal{S}_\Sigma > 1$ — the anti-screening expected of Rule 10) live on the low-gradient branch. (The sign-safe form $|X|$ is required: on the static branch $X < 0$, and the power law is otherwise defined only for even integer powers. The $X|X|$ representation is understood piecewise on the timelike and spacelike kinetic branches, with continuous matching at $X = 0$; where a C^∞ regulator is required numerically, $X|X|$ may be replaced by $X\sqrt{X^2 + \epsilon_X^2}$ with ϵ_X taken below all resolved physical kinetic scales, leaving the quoted asymptotic screening laws unchanged. The zero-gradient limit of the selected sector — where $P_{,X} \rightarrow 0$ — is correspondingly unregulated by the theory alone and requires the nonzero ambient field of the nested hierarchy; see the open-item statement below.) The static spherical field equation $\partial_r(r^2 P_{,X} \phi') = r^2 \mathcal{Q}$ integrates to $P_{,X} \phi' = \mathcal{C}/r^2$: a configuration immersed in an ambient gradient answers an incremental source charge only through the inverse stiffness, so the observable Temporal Shear is suppressed by

$$\mathcal{S}_\Sigma(\mathcal{E}) = \frac{1}{P_{,X}(X_{\text{amb}})} = \left[\frac{k}{\sqrt{2}} \frac{g}{g_t} + \left(\frac{g}{g_t} \right)^2 \right]^{-1}, \quad g_t = \frac{cH_0}{2|\beta_A|} \simeq 3.4 \times 10^{-10} \text{ m s}^{-2}, \quad (17)$$

whose leading quadratic-dominated tail is $(g_t/g)^2$ on the high-gradient branch ($g \gg g_t$, all Solar-System benchmarks) and its low-gradient tail is $\mathcal{S}_\Sigma \rightarrow \sqrt{2}g_t/(kg)$ at $g \ll g_t$ — the branch that generates the flat galactic asymptote. The shear-to-acceleration map $\Sigma = 2\beta_A^2 g/c^2$ converts the kinetic ratio $|X|/\Lambda_X^4 = \frac{1}{2}(g/g_t)^2$ into the gradient channel of the covariant environmental operator constructed phenomenologically in Paper 26 §2.5. The kinetic scale is the single scale of the sector, fixed by the cosmological shear floor: $\Lambda_X^4 = M_{\text{Pl}}^2 H_0^2$, i.e. $\Lambda_X = \sqrt{M_{\text{Pl}} H_0} \simeq 1.9 \text{ meV}$, the dark-energy scale. The shear threshold therefore carries no free parameter. The two-body response is obtained by solving the same equation for the pair's mutual shear: flux conservation $P_{,X} \phi' = \mathcal{C}/r^2$ with $P_{,X} \simeq 2|X|/\Lambda_X^4 \simeq \phi'^2/\Lambda_X^4$ where the quadratic term dominates ($\xi \gg \xi_*$, the mutual-dominated shell interior) gives the high-gradient asymptote $\phi' \propto r^{-2/3}$. In the isolated spherical, potential-negligible source-flux control, define $q = g_N/g_t = (r_*/r)^2$ and $y = |\phi'|/|\phi'_{\text{lin}}|$. The exact selected-sector relation is

$$\frac{k}{\sqrt{2}} q y^2 + q^2 y^3 = 1, \quad \xi = \frac{1}{2}(qy)^2, \quad r_* = \sqrt{GM/g_t}. \quad (18)$$

Thus $y \sim (r/r_*)^{4/3}$ where the quadratic term dominates, while the low-gradient branch has $y \sim (\sqrt{2}/k)^{1/2}(r/r_*)$. The expression $y[1 + y^2(r_*/r)^4] = 1$ belongs to the retained unit-term control. Embedding and pair geometry enter through the solved ambient and pair response; the isolated spherical identity is not a complete two-source field solution. The quoted pairwise projection is $\mathcal{S}_{\text{eff}}(s) = \mathcal{S}_\Sigma(X_{\text{env}})^2 y(s)$ under its stated source and ambient assignments.

and the full pairwise response propagates this mutual shear with the ambient inverse-stiffness factor at the emission and response vertices,

$$\mathcal{R}(s) = \mathcal{S}_\Sigma(X_{\text{env}})^2 y(s), \quad (19)$$

where X_{env} is the embedding ambient kinetic value of the hierarchy level above the pair (specifically the external Galactic ambient floor $2X_{\text{gal}}/\Lambda_X^4 \approx 0.52$ for field wide binaries — a value originally calibrated to the wide-binary plateau under the pre-propagator bookkeeping; the directly measured solar-circle field gives the independent estimate $u_{\text{sun}} = a_\odot/g_t \simeq 0.57$, $2X_{\text{sun}}/\Lambda_X^4 \simeq 0.32$ ($v_c = 220 \text{ km s}^{-1}$, $R_0 = 8.1 \text{ kpc}$; step 32), which the fully-coupled propagator-plus-vertex reading of Paper 13, step 017, uses to reproduce the plateau amplitude at the percent level without calibration — the ambient bracket $u_0 \simeq 0.55\text{--}0.72$ is a physical range, not a tuned value, because the ambient field is itself a solved quantity, or the dominant member's pre-existing shell for hierarchical pairs), excluding the pair's own co-generated mutual field $g_{\text{mut}} = GM/s^2$ to avoid suppressing a response by the response itself in the transition region. Under the selected stiffness the ambient vertex evaluates to $\mathcal{S}_\Sigma(\xi_{\text{env}} \sim 0.3\text{--}0.5) \approx 0.08\text{--}0.10$ — the

external-field suppression of order 10^{-2} in $\mathcal{S}_\Sigma^2$ that emerges as the AQUAL-type external-field effect rather than as calibration; on the rejected unit-term baseline the same ambient returned $\mathcal{S}_\Sigma \approx 0.5\text{--}0.6$. Evaluated on the corrected ambient semantics (derived ambient, pure propagator, deprojected separation), the zero-free-parameter joint test on the wide-binary saturation amplitude and transition scale passes at 0.44σ and 1.69σ respectively (predicted $\alpha_{\text{sat}} = 0.371$ against the identity $4\sqrt{2}/k \simeq 0.353$; $R_s = 3,676$ AU), while the unit-term baseline and the exponential-interpolation rival are excluded at the $\sim 30\sigma$ level on amplitude (master-sector ledger, step 56/020). Two regimes of this single operator follow directly. For a comparable-mass pair the mutual field is the measured response — the two members' gradients oppose and cancel at the pair's bridge region — so the vertex ambient saturates at the external environmental floor and the observable transition profile is the flux-conserving $\mathcal{R} \sim s^{4/3}$ law, the exponent the wide-binary population selects. For a hierarchical pair — a test member embedded in a dominant member's pre-existing nonlinear shell — the dominant member's field is itself the embedding ambient; the full flux identity $P_{,X}(X_{\text{dom}}) = 1/y$ in the isolated potential-negligible dominant-source control then makes the vertex factors equal to $y(s)$, giving $\mathcal{R} = y^3 \sim s^4$: the steep deep-interior response required by the Solar-System benchmarks (constraint F4) is recovered exactly, with the radius law $R_s = r_* = \sqrt{GM/g_t}$ and the transition-radius scaling derived from the action rather than fitted. Evaluated at zero free parameters, the operator returns $\mathcal{R} \simeq 2.2 \times 10^{-15}$ for the Earth–Moon pair (the vertex ambient there carries both Earth's nonlinear field and the solar field at 1 AU; the corpus's earlier 2.5×10^{-14} bookkeeping is reproduced at the same order), 1.0×10^{-23} at the Cassini conjunction (earlier bookkeeping $\sim 6 \times 10^{-23}$), 2.7×10^{-11} at Saturn's orbit (earlier bookkeeping $\sim 10^{-10}$), and 1.2×10^{-21} for the terrestrial shear environment — the value independently quoted by the covariant-operator evaluation of Paper 26 — while the derived wide-binary transition scale $R_s = \sqrt{GM/g_t} \simeq 4.7$ kAU at $1.24 M_\odot$ overshoots the fitted 2646 ± 182 AU by a factor $\simeq 1.8$. The residual is stated plainly: a normalization of the same functional form, with the transition acceleration fitted directly to the wide-binary data, could reproduce the fitted radius nearly exactly — but that agreement would be by construction rather than prediction. The derived $g_t = cH_0/(2|\beta_A|)$ contains no adjustable constant, so the factor $\simeq 1.8$ constitutes the first genuinely independent comparison of the scale. Its sign is the one the environmental baseline predicts: the operator measures the pair's internal gradient against the ambient environmental floor, which inside the Galactic disk exceeds the asymptotic cosmological value $\Sigma_{\text{bg}} = H_0/c$. Specifically, the ambient Galactic temporal potential exceeds the pair's mutual gravitational potential by $\Phi_{\text{gal}}/\Phi_{\text{pair}} \approx (v_0^2/c^2)/(GM_{\text{pair}}/(sc^2)) \sim 9 \times 10^4$ at the fitted separation $s = 2646$ AU (with Galactic rotational potential $\Phi_{\text{gal}}/c^2 \approx 5.4 \times 10^{-7}$ dominating the mutual well $\Phi_{\text{pair}}/c^2 \approx 4.6 \times 10^{-12}$, even while the local mutual acceleration gradient dominates the ambient Galactic acceleration, $g_{\text{gal}}/g_{\text{pair}} \approx 0.06$). Under the isolated-profile reading the ambient floor enters the operator only through the vertex factor $\mathcal{S}_\Sigma(X_{\text{env}})^2$, modulating the response amplitude rather than the shape scale r_* ; a same-estimator comparison (folding the mass-convolved derived profile through the paper's own sem-weighted single-scale exponential estimator; Paper 13 step 017) then returns $\simeq 5.1$ kAU against the measured 2646 ± 609 AU — ratio $\simeq 1.9$ — with the half-excess marker agreeing at $\simeq 3.4$ kAU against the observed $\simeq 1.7\text{--}1.9$ kAU. The earlier heuristic explanations fail quantitatively: the exponential-fit scale reduction is $\lesssim 2\%$ (the gradual $s^{4/3}$ recovery pulls the fitted scale upward, not downward), $\sqrt{M}$ -weighting accounts for only $\sim 4\%$, and mass convolution broadens the transition toward larger fitted scales. The resolution is not a new coefficient but the embedded problem: the ambient enters not only at the vertices but in the perturbation propagator itself. The residual is substantially resolved by the propagator the ambient itself supplies. Solving the source perturbation on the Galactic nonlinear background (step 32: the full nonlinear elliptic problem $\nabla \cdot [P_{,X} \nabla \phi] = \rho$ around a uniform ambient $u_0 = \sqrt{X_{\text{gal}}} \simeq 0.72 g_t$) shows the background stiffness $Z_{ij} = P_{,X} \delta_{ij} + 2P_{,XX} a_i a_j$ — anisotropic, $Z_{\parallel} = 1 + 3X_{\text{gal}} \simeq 2.56$ parallel and $Z_{\perp} = 1 + X_{\text{gal}} \simeq 1.52$ transverse — suppressing the pair's orientation-averaged far-field response to $y_{\text{far}} \simeq 0.56$ and compressing the half-excess transition marker to $\simeq 0.44 r_*$ (from $0.74 r_*$ isolated, fitted-scale ratio $\simeq 0.60$). Folded through Paper 13's own mass distribution and sem-weighted estimator (step 017), the embedded prediction returns $R_s \simeq 3,300$ AU against the fitted 2646 ± 609 AU and a half-excess marker at $\simeq 1,715$ AU, coincident with the observed value — a residual factor $\simeq 1.26$ inside the systematic band. The $\eta_{\text{env}} \simeq 3.7$ coefficient required by the isolated-profile reading is therefore not a tuning parameter: the ambient stiffness supplies the transition-scale compression as a derived consequence of the same kinetic term. Two sub-questions remain open and are now sharp rather than diffuse: the amplitude factorization — the observed $\alpha_{\text{sat}} = 0.366$ lies between the pure-propagator reading ($\simeq 0.455$) and the propagator-times-vertex reading ($\simeq 0.24$), so the data discriminate the division of environmental suppression between source charge, propagator and response vertex — and the environmental ordering, which refines under the corrected ambient variable: the operator's environmental coordinate is the field gradient $X = (\nabla \phi)^2/\Lambda_X^4$, not the density, and the observed subsamples show the midplane more suppressed under either estimator — the free- α fits give $(R_s, \alpha) = (2,821 \text{ AU}, 0.244)$ at $|Z| < 0.1$ kpc versus $(4,681 \text{ AU}, 0.401)$ at $|Z| > 0.15$ kpc — and inverting the amplitudes on the fully-coupled sweep requires the effective ambient to be $\sim 36\%$ stronger at the midplane ($u_{\text{eff}} \simeq 0.71$ versus $\simeq 0.52$ in the halo; Paper 13). The supply-versus-demand check (Paper 13, step 017) closes the naive rescue: Galactic geometry supplies only $\sim 4\%$ between the subsample median heights — the vertical field contributes $u_z \simeq 0.17$ at 248 pc against a common radial floor $u_r \simeq 0.57$ pinned by the locally measured centripetal acceleration, which cannot be screened down inside the disk without contradicting the observed dynamics. The linear supply fails on both counts: $u = |a|/g_t$ grows with $|Z|$ — the wrong sign for an ordering that strengthens toward the midplane — and supplies only $\sim 4\%$ of the required contrast. That estimator is the weak-field exterior reading: inside the nonlinear disk the local acceleration is not the ambient field state. The ordering is produced instead by the landscape's nonlinear response to density on the same operator's k -branch: the embedded pair-scale solve (step 67; Paper 13 AUD-3) shows the response charge carried by the ambient boundary variable, $D^{-1} \propto u_{\text{amb}}^{-2,0}$ with background-density sensitivity below 0.02% , and the local k -branch balance $P_X u = 4\pi G \rho L/g_t$ with $P_X \sim Ku/\sqrt{2}$ yields the ambient map $u_{\text{amb}} = \sqrt{4\sqrt{2}\pi G \rho L/(Kg_t)}$. Calibrated once at the midplane inversion, $L \simeq 0.84$ kpc reproduces all five Galactic strata within $\simeq 10\%$ and the endpoint ordering exponent $p \simeq 0.46\text{--}0.5$ — the environmental dependence is thereby an operator output, not a phenomenological proxy. The environmental dependence of the measured transition scale is a genuine empirical datum rather than an operator output: the wide-binary stratifications measure R_s rising with ambient

density ($R_s \propto \rho_{\text{amb}}^p$; free-fit exponent $p \approx 0.4 \pm 0.1$, centered between the $\rho^{1/3}$ and $\rho^{1/2}$ ambient channels, Paper 13), i.e. pairs embedded in more strongly screening environments retain suppression to larger separations — the ordering stated in constraint F5. The derived scaling $R_s \propto M^{1/2}$ differs from the $M^{1/3}$ read of the wide-binary demographic splits; that read is independently flagged as degenerate with the disk size–mass relation, so the derived exponent constitutes the sharper discriminant for that test.

Scope of the two-body projection. The $\mathcal{R}(s)$ law is an effective projection of the static scalar solution, not an exact solution for unequal finite-sized bodies in a solar background. On the static branch $J_i = P_{,X} \partial_i \phi$ can have $dJ = dP_{,X} \wedge d\phi \neq 0$ when the solved kinetic stiffness varies transversely; by contrast the conformal force derives from $d \ln A(\phi)$ and remains exact. A low-gradient bridge may locally reduce $P_{,X}$, but it does not by itself unscreen a body's integrated scalar charge or evade LLR: the external solar gradient, finite source size, nonlinear flux conservation, and boundary conditions all enter the force and synodic range observable. In particular, the selected two-branch sector has no canonical point: $P_{,X} \rightarrow 0$ as $X \rightarrow 0$, so the zero-gradient vacuum limit is regulated not by the theory but by the nonzero ambient of the nested hierarchy — a stated open condition on global solutions rather than an established bound. The dimensionless two-centre calculations in steps 59, 72 and 75 test this limitation under specified sources and boundaries, including arbitrary pair-to-ambient orientations on a Cartesian grid (step 75); Paper 17, step 086 solves a coupled smoothed Earth–Moon source benchmark in a uniform solar-gradient background at syzygy; it does not resolve the physical body interiors or the solar tide. An observable-level lunar range fit remains required before revising the quoted LLR bound.

The physical-scale Earth–Moon–Sun bridge is evaluated in Paper 17 at two levels. Step 086's coupled source solve in the specified solar background supersedes Step 084's matched-profile diagnostic for that collinear benchmark: at Full-Moon syzygy ($u_0 > 0$) the field along the pair axis stays at $|\nabla \phi|_{\min} \approx 335 g_t$ ($P_{,X} \sim 1.2 \times 10^5$), and at New-Moon syzygy ($u_0 < 0$), where the axial gradient crosses zero at $z/d \approx 0.432$ (axial cell-centre minimum $|\nabla \phi|_{\min} \approx 36.3 g_t$, $P_{,X} \sim 1.7 \times 10^3$), off-axis stiffness still keeps the resolved $P_{,X} < 1$ volume fraction at zero. An LLR range-model integration of the residual force is the remaining observable-level step. The shared action and exact/non-exact transport distinction are specified here, while the LLR-specific observational comparison resides in Paper 17.

With this projection the single operator satisfies the stated benchmark constraints (Appendix E, R2): it recovers the Temporal Shear at wide-binary scales, suppresses the pairwise Solar Temporal Shear to $\sim 10^{-23}$ at the conjunction separation $s = 1.6 R_\odot$ and $\sim 10^{-10}$ – 10^{-11} at Saturn (9.5 AU), and yields a pairwise Earth–Moon benchmark far below the nominal LLR acceleration scale (the definitive observable comparison remaining the range-model integration described above), while suppressing the Earth-vicinity pairwise response $F(7013 \text{ km}) \rightarrow 0$. This is a statement about $\mathcal{S}_\Sigma$ alone: the clock sector is a different projection, and neither the terrestrial static-depth factor $S_A^{(\oplus)}$ nor the covariance functional C_A is suppressed by $\mathcal{S}_{\text{eff}}(s)$, so the GNSS clock-rate and covariance observables are unaffected.

Environmental response and the scale dictionary. The master action uses distinct kinetic, potential and geometric-density parameters: $\Lambda_X = \sqrt{M_{\text{Pl}} H_0} \simeq 1.9 \text{ meV}$, $\Lambda_V = \lambda^{1/4} M_{\text{Pl}}$, and ρ_T . Expressing the calibrated density as an energy gives $\rho_T^{1/4} \simeq 96 \text{ keV}$; this conversion does not make it a second value of Λ_X or the potential normalization. The continuous hierarchy is supplied by the environmental solution $\phi_\mathcal{E}$ and its gradients. Where the local adiabatic approximation applies, $V_{,\phi} + \rho_* A_{,\phi} = 0$ and the source-plus-potential curvature is $m_\mathcal{E}^2 = V_{,\phi\phi}(\phi_\mathcal{E}) + \rho_* A_{,\phi\phi}(\phi_\mathcal{E})$; the kinetic principal coefficients follow from the same selected $P(X, \phi)$ evaluated on that solution. These quantities vary with density, compactness and boundary geometry while the declared action parameters remain fixed. This is environmental response, not an independently derived renormalization-group law for a density-dependent Λ . The scale audit of Paper 6, Appendix C, already distinguishes these roles.

Amplitude sector. The clock-amplitude projection is fixed by the potential sector. In the unified master potential $V(u) = V_{\text{matter}}(u) e^{-(u/u_s)^4} + V_0 e^{-(u_s/u)^4}$ of Section 8, the matter-hosting weak-field branch is realized by $V_{\text{matter}}(u) = \frac{\lambda}{4} M_{\text{Pl}}^4 u^4 = \frac{\lambda}{4} \phi^4$. For field values $u = \phi/M_{\text{Pl}} \ll u_s \simeq 10$, the non-perturbative horizon factor $e^{-(u_s/u)^4}$ vanishes to all orders in Taylor expansion around $u = 0$ (underflowing identically to zero at physical screening densities), while $e^{-(u/u_s)^4} \rightarrow 1$, reducing the master potential identically to the quartic self-interaction across the matter-hosting domain. The quartic is the minimal admissible self-interaction on the $\beta_A = -1$ branch: an inverse-power form admits no stable minimum on this coupling branch (constraint F1), while a quadratic potential lacks the required density dependence. Minimizing the matter-sourced effective potential $V_{\text{eff}} = \frac{\lambda}{4} \phi^4 + \rho A(\phi)$ on the $A(\phi) = e^{-\phi/M_{\text{Pl}}}$ branch yields the equilibrium field $\phi_{\min} = (\rho/\lambda M_{\text{Pl}})^{1/3}$ and an effective scalar mass $m_{\text{eff}} = \sqrt{3} \lambda^{1/6} (\rho/M_{\text{Pl}})^{1/3}$. The associated Compton wavelength $\lambda_c = m_{\text{eff}}^{-1}$ satisfies a universal, density-independent relation with the geometric saturation radius $R_T = (3M/(4\pi\bar{\rho}))^{1/3}$, namely $\lambda_c/R_T = 3^{-1/2} (4\pi/3)^{1/3} \lambda^{-1/6} (M_{\text{Pl}}/M)^{1/3} (\approx 4.07 \text{ for Earth at the reference coupling } \lambda_{\text{ref}} \approx 7.5 \times 10^{-71}, \text{ and } \approx 0.60 \text{ at the } 10^5\text{-rescaled coupling; Appendix E, steps 03, 53}).$ Because the direct nonlinear radial boundary-value solve on the selected two-branch kinetic sector places Earth on the flux-following (leaking) branch ($u_{\text{int}}/u_{\text{eq}} \simeq 1.45 \times 10^{-7}$, `step_53_unified_profile_two_branch.json`), the interior clock field is set by the transmitted Galactic/cosmological ambient rather than an isolated-body chameleon minimum, while S_A acts as the empirical geometric saturation-depth index relative to $R_T(M)$. The reference normalization is a fiducial point of the potential family, not the operative weak-field value: the corrected linear-in- $\mathcal{S}_\Sigma$ Cassini evaluation fails at λ_{ref} by $\sim 250 \times (\gamma_{\text{PPN}} - 1 \approx -5.8 \times 10^{-3}$ versus the 2.3×10^{-5} bound) and requires the $\times 10^5$ -rescaled branch, so wherever the quartic normalization enters the corpus adopts $\lambda_{\text{Cassini}} = 10^5 \lambda_{\text{ref}} \approx 7.5 \times 10^{-66}$ (step 03; shared corpus constants `LAMBDA_QUARTIC_REF/LAMBDA_QUARTIC_CASSINI`). The two quoted values are the reference and Cassini-compatible points of the same quartic normalization, not two independent couplings. The transition density ρ_T is calibrated through Earth's saturation radius: identifying R_T with the terrestrial GNSS clock-covariance correlation length

$\lambda_T \approx 4200$ km fixes $\rho_T = 3M_\oplus/(4\pi R_T^3) \approx 19.2\text{--}20$ g cm $^{-3}$ from real timing residuals. The measured correlation length is an estimator-dependent family rather than a point value — the precise-product bracket spans $\sim 1.9\text{--}4.5 \times 10^3$ km (MGEX 1862 ± 155 km; IGS inter-center $3,330\text{--}4,549$ km), with the $\sim 30\text{--}40\%$ epoch/window scatter the dominant systematic, propagating to an effective ρ_T band of roughly $8\text{--}70$ g cm $^{-3}$; raw single-point channels bound the scale from below at $\sim 0.7\text{--}1.1 \times 10^3$ km (Papers 1, 3, 6, 14). The quoted $4,200$ km is the IGS precise-product convention adopted as the corpus normalization; the estimator-independent cross-checks on that normalization — the atomic-scale radius $R_T(m_p) \sim a_0$ and the magnetar critical period — are catalogued in Paper 6. Here ρ_T is the formal reference constant of the saturation scaling law $R_T(M) = (3M/4\pi\rho_T)^{1/3}$ — the mean density a body would carry if its entire mass occupied the saturation radius — not the local density of Earth's interior at $r = R_T$ (the lower-mantle value there is ≈ 5.5 g cm $^{-3}$, and no terrestrial material reaches 20 g cm $^{-3}$); the physical content of the calibration is the radius R_T itself and its tested mass scaling, not a density claim about Earth's structure. This in turn determines the unsaturated clock-amplitude factor $S_A = \min[1, (\bar{\rho}/\rho_T)^{1/3}]$ with no additional free parameter once the empirical ρ_T calibration is fixed, returning the transitional value $S_A^{(\oplus)} \simeq 0.65$ ($0.43\text{--}0.88$ across the ρ_T band) at Earth mean density $\bar{\rho}_\oplus = 5.515$ g cm $^{-3}$. Furthermore, at its matter-sourced equilibrium the quartic energy density obeys $V(\phi_{\min}) = \rho \phi_{\min}/4$ — always a negligible fraction of the local matter density wherever the truncation is solved ($\approx 3 \times 10^{-8}$ g cm $^{-3}$ at terrestrial conditions against $\bar{\rho}_\oplus = 5.5$ g cm $^{-3}$, $\sim 10^{-41}$ g cm $^{-3}$ at interstellar densities, $\sim 10^{-49}$ g cm $^{-3}$ in voids) — so the quartic sector carries no appreciable energy budget in any matter-hosting environment and remains dynamically flat exactly where it is the operative potential. Its certified domain is the weak-field regime $u \ll u_s$: at cosmological field excursions $u \sim \ln(1+z) \sim 1$ the operative potential is the master family's $V_{\text{matter}}(u)$ branch itself, not the weak-field truncation, and the flatness-compatibility condition constrains that branch directly — the non-perturbative floor $V_0 e^{-(u/u)^4}$ remains identically zero there and leaves the constraint free. The floor activates only at horizon pileup scales $u \sim u_s \simeq 10$. Shear suppression ($\mathcal{S}_\Sigma$) and clock amplitude (S_A) are thereby distinct, mutually consistent projections of one scalar-sector completion, not independent mechanisms. The two sector scales are likewise distinct by construction: the kinetic completion is normalized by $\Lambda_X = \sqrt{M_{\text{Pl}} H_0} \simeq 1.9$ meV, the gradient/shear threshold anchored to the measured drift; the potential sector is normalized by the dimensionless λ , equivalently $\Lambda_V \equiv \lambda^{1/4} M_{\text{Pl}} \simeq 1.3 \times 10^2$ GeV on the operative branch; and ρ_T is a third, geometric quantity — the constant of the $R_T(M)$ law — whose energy-density reading $\rho_T^{1/4} \simeq 96$ keV is not the potential normalization. Identifying ρ_T with Λ_V^4 would fix $\lambda = \rho_T/M_{\text{Pl}}^4 \simeq 2.5 \times 10^{-90}$, a branch excluded because it drives $u_{\min}$ past the knee u_s inside ordinary neutron-star cores and yields a Compton length vastly exceeding any terrestrial body (Paper 6, Appendix C). The order-unity self-quenching crossing instead sits at $\rho_{\text{sat}} \sim \lambda M_{\text{Pl}}^4 \sim 10^{26}$ g cm $^{-3}$, inside the temporal-well domain.

Status of the derivation. What is derived here is a selected realization, not a uniqueness theorem: the static-branch operator structure, the scale g_t , the radius law $R_s = \sqrt{GM/g_t}$, the flux-conserving profile $y[1 + y^2(r_*/r)^4] = 1$ on the quadratic-dominated branch, and the two-body vertex structure $\mathcal{R} = \mathcal{S}_\Sigma(X_{\text{env}})^2 y(s)$ follow from the specified $P(X, \phi)$ — yielding the $s^{4/3}$ transition steepness for comparable-mass pairs (confirmed by the wide-binary forward model) and the s^4 deep-interior asymptote for hierarchical pairs (constraint F4). The completion is now selected by data, not merely admissible: the corrected wide-binary joint test passes the two-branch sector at zero per-system free parameters and excludes the unit-term baseline and the exponential-interpolation candidate at $\sim 30\sigma$ on amplitude, while the SPARC radial-acceleration fit under the same sector (Paper 6, Steps 10, 13; with $k_* = 4\sqrt{2} g_t/a_0 = 16.03$ calibrated to a_0 and canonical zero-gradient regulator $P_{,X}(\xi) = \epsilon_{\text{reg}} + k\sqrt{\xi} + 2\xi$, $\epsilon_{\text{reg}} = 10^{-3}$ ensuring strict hyperbolicity at $X = 0$) returns RMS 0.2185 dex at $\Upsilon_d = 0.5$ and 0.2004 dex at $\Upsilon_d = 0.35$ under the action-derived additive force law $g_{\text{obs}} = g_N + a_\phi$ — matching the empirical MOND interpolating-function reference (0.1989 dex) at $\Upsilon_d = 0.35$ and outperforming the unit-term baseline (0.2812 dex) and exponential-interpolation candidate (0.2749 dex) by > 60 mdex (while the phenomenological quadrature comparator $\sqrt{g_N^2 + a_\phi^2}$, which removes the $+2g_N a_\phi$ crossover cross-term of the two-term flux law at $\Upsilon_d = 0.5$, gives 0.1974 dex with $k_{\text{fit}} = 15.78$ and outer-edge BTFR median $v_{\text{obs}}/v_{\text{pred}} = 1.0109$ vs 0.910 additive at $\Upsilon_d = 0.5$). The ellipticity and fluctuation-sector certificates already cover this noncanonical completion: step 61 scans the static and cosmological branches of all three candidate sectors and certifies strict hyperbolicity and no-ghost conditions ($Z_\perp = P_{,X} > 0$, $Z_\parallel = P_{,X} + 2\xi P_{,XX} > 0$, $Z_t > 0$) across all regimes, with the two-branch cosmological sound speed subluminal ($c_s^2 \in [1/3, 1/2]$), the static spacelike longitudinal fluctuation speed $v_\parallel^2 = (P_{,X} + 2XP_{,XX})/P_{,X} \in [2, 3]$ (a generic property of $P_{,XX} > 0$ AQUAL/ k -essence sectors that preserves macro-causality and admits no closed causal curves because the acoustic cone remains strictly hyperbolic with respect to the global cosmic time foliation; Babichev, Mukhanov & Vikman 2008, contrasting with the flat-space UV analyticity bounds of Adams et al. 2006), and the late-time growth enhancement weakened to $G_{\text{eff}}(z=0) \simeq 1.16 G$ — directionally consistent with structure-growth measurements below Λ CDM, and the surviving discriminant against the exponential-interpolation rival, which retains the baseline $\approx 2G$ boost. Remaining open calculations: uniqueness across the wider $K(X)$ class (cuscutoon-type members carrying no propagating scalar degree of freedom) and the microscopic form of the disformal sector $B(\phi)$. The $X \rightarrow 0$ regulator question is now quantified: in the realized nested hierarchy, astrophysical systems are embedded in the nonzero Galactic and cosmic ambient floor ($\xi_{\text{env}} \simeq 0.32\text{--}0.52$, where $P_{,X} \simeq 9.7\text{--}12.6$ is well away from strong coupling), while at isolated saddle points where $\nabla\phi_{\text{tot}} = 0$ a canonical regulator $P_{,X} = \epsilon + k\sqrt{\xi} + 2\xi$ is invisible to the growth budget at any tested ϵ (step 62: χ^2 changes by 0.09 for $\epsilon = 0 \rightarrow 1$ — the $\sim 30\sigma$ and growth exclusions of the unit-term candidates trace to their asymptotic behaviour, not to data discrimination of a small constant), and the SPARC window tolerates $\epsilon \lesssim 0.1$ at zero data cost with a marginal improvement (rms 0.2098 dex), before order-unity values reintroduce a Keplerian tail below $g_{\text{bar}} \sim (\epsilon/k)g_t$. The admissible regulator class is therefore a small constant $\epsilon \lesssim 0.1$ (together with the physical ambient floor), sufficient for well-posedness at the marginal-ellipticity point without disturbing any tested observable.

The Nested Hierarchy and the Pairwise Projection. The use of a two-body operator does not imply the universe consists of isolated pairs in a vacuum. The full reality is a continuous nested hierarchy: a global cosmological baseline hosts galactic ambients, which in turn host solar and terrestrial wells. At Earth's surface, the field decomposition is overlapping and nested (approximately 93% galactic, 6.5% solar, 0.5% terrestrial). The two-body operator $\mathcal{S}_{\text{eff}}$ is simply the effective pairwise projection of the master environmental operator $\mathcal{S}_{\Sigma}(\mathcal{E})$ — whose covariant EFT form, unifying the gradient and density control parameters, is constructed in Paper 26 §2.5 — when solving a specific two-body Keplerian orbit (such as Saturn around the Sun, or wide binaries). It describes how the mutual separation s allows the local gradient to recover against the ambient Galactic floor.

Finite-probe boundary effects. Coherent transponder phase turnaround cancels the endpoint conformal clock factor in the idealized link, but it is not a proof that every propagation or finite-probe correction to a complete round trip vanishes. A spacecraft's density alone does not set the extent of a kinetic screening region: its scalar charge, ambient gradient, body size, and the time-dependent boundary-value solution determine any such effect. A moving, non-reciprocal disformal boundary contribution must be derived from the same matter metric and checked against the actual uplink/downlink geometry; it cannot be inferred from a curl of $P_{,X}d\phi$ or from the spacecraft's speed alone. The present analysis neither explains the published coherent flyby residuals by this mechanism nor supplies a bound on it.

The Flyby Reduction Artefact. Because the two-body operator strongly screens the Earth-vicinity Temporal Shear, the $\sim 10^{-3}$ m/s Earth flyby anomaly in Δv cannot be a Temporal Shear anomaly. Instead, it is identified as a candidate Clock-Sector Reduction Artefact. Orbit determination codes reconstruct velocities using an assumed GR time standard; highly asymmetric, fast hyperbolic flybys accumulate rapid proper-time offsets at perigee due to the Temporal field's gradient, which are misread by the separate pre- and post-encounter fits as a ΔV discontinuity where the tracking link carries the spacecraft's own time reference. The channel accounting is exact: in a fully coherent two-way transponder link the endpoint conformal factors cancel identically at the turnaround ($\nu_{\text{ret}} = R\nu_u$), so the term survives only in clock-carrying observables — one-way, non-coherent, or regenerative-ranging links and onboard-clock telemetry — while the published anomaly catalogue was recorded in the coherent class (Paper 15 §5.2). The artefact is therefore a falsifiable prediction for clock-carrying flyby passes — a $c\eta \sim$ m/s raw signature at perigee — rather than an attribution of the recorded anomalies. This is consistent with the absence of the effect in circular orbits (GP-B, LAGEOS, GRACE), and with its intermittency across hyperbolic encounters, which a geometry- and pipeline-dependent reduction artefact predicts but a fixed dynamical anomaly does not.

Cassini constraint interpretation. The Cassini Shapiro-delay measurement is a round-trip radio ranging experiment performed during solar conjunction. The signal path samples the Sun's deep potential well, which in TEP corresponds to the strongly screened solar environment of the single-body response. The bound $S_{\Sigma}^{(\odot)} \lesssim 1.15 \times 10^{-5}$ (5.8×10^{-6} on the isotropic benchmark; $|\gamma_{\text{PPN}} - 1| \simeq 4.32 \times 10^{-8}$ at $1.6 R_{\odot}$ on the selected two-branch kinetic sector) applies to the solar-vicinity environment along the signal path, not to the dilute interstellar medium where the effective coupling recovers for wide-binary dynamics. The pairwise factor $\mathcal{S}_{\text{eff}}(s)$ governs two-body orbital dynamics and is not the projection tested by a massless probe; the Cassini channel is therefore governed by the effective screened single-source solar response, represented in the PPN limit by $S_{\Sigma}^{(\odot)}$ through the screened-limit PPN relation $\gamma_{\text{PPN}} - 1 = -2\beta_A^2 S_{\Sigma}/(1 + 2\beta_A^2 S_{\Sigma})$ of §7 (Step 80).

Wide-binary and cross-scale consistency. The wide-binary velocity excess (Paper 13, $\alpha_{\text{sat}} = 0.366 \pm 0.012$, $R_s = 2,646 \pm 182$ AU statistical, ± 609 AU total including systematic uncertainty) is a geodesic kinematics observable. The cross-scale architecture rests on the universal two-body operator $\mathcal{R}(s) = \mathcal{S}_{\Sigma}(X_{\text{env}})^2 y(s)$. The ten-order-of-magnitude gap between the Cassini and wide-binary response requirements is resolved naturally by the nested structure of that single operator: hierarchical Solar-System pairs sit deep inside the dominant member's shell where $\mathcal{R} \sim s^4$ ($\sim 10^{-23}$ at the conjunction separation, $\sim 10^{-11}$ at Saturn), while comparable-mass field binaries sample the saturated-ambient regime where the transition profile is $\mathcal{R} \sim s^{4/3}$. The cross-scale structure spans from the solar-conjunction separation $s = 1.6 R_{\odot}$ through 1 AU (LLR), 9.5 AU (Saturn), and up to 2,646 AU (wide binaries), satisfying the stated cross-scale benchmark constraints within the effective response model; the Cassini bound itself acts on the single-body charge $S_{\Sigma}^{(\odot)}$ rather than on this pairwise factor. The terrestrial scale is independently resolved, as the Earth-vicinity Temporal Shear is strongly screened, moving the Earth-flyby anomaly into the clock sector as a reduction artefact — scoped to the link classes that carry the term (Paper 15 §5.2).

Recovery operator — defining constraints. Locally the time field recovers Temporal Shear (a geometric acceleration) only in low-acceleration, two-source configurations, and saturates everywhere else. The recovery operator is fixed by six constraints: F1 — excludes the inverse-power thin-shell branch: with $\beta_A = -1$, the inverse-power potential has no admissible minimum and predicts the wrong environmental direction; F2 — not a universal hard-gradient cap (a constant gradient-cap scale $g_{\text{cap}} \sim g_{\text{TEP}}$ would leave an unsuppressed Solar-System acceleration floor $\approx 2\beta^2 g_{\text{cap}} \approx 10^{-9}$ m s $^{-2}$, $10^5 \times$ the Saturn bound); F3 — $K > 3\Omega_m$ (kinetic-sector stability bound); F4 — per-system recovery steepness $k \geq 4$ in separation, derived from the Saturn ephemeris bound and the wide-binary transition radius; the corresponding two-body configuration-dependent realization is developed in the companion screening analyses; F5 — transition radius larger in denser environments, amplitude rises with mass ratio q , transition radius scales with primary mass while amplitude falls with it (weaker self-screening in lower-mass systems revealing larger unsuppressed response; measured, Paper 13; the demographic read $R_s \propto M^{1/3}$ is degenerate with the disk size–mass relation, while the derived kinetic completion predicts $R_s \propto M^{1/2}$); F6 — environmental coupling normalisation differs by ≈ 4 –6% between host disks and anchors (measured, Paper 11). The six conditions F1–F6 are the physical consistency constraints satisfied by the derived kinetic completion; the scaling is derived from the master action $P(X, \phi) = -V(\phi) + \frac{2k}{3\Lambda_X^4} X|X|^{1/2} + X|X|/\Lambda_X^4$ ($k \simeq 16$ fixed by a_0)

rather than prescribed ad-hoc. F3 is the screening-sector counterpart of the invertibility, hyperbolicity, and no-ghost conditions of Section 4: those conditions are certified for the adopted noncanonical completion by the sector scan of Appendix E (step 61), which confirms strict positivity of the principal coefficients and hyperbolicity/no-ghost conditions ($Z_\perp > 0$, $Z_\parallel > 0$, $Z_t > 0$) across all regimes: on the cosmological timelike branch the scalar fluctuation sound speed is subluminal ($c_s^2 \in [1/3, 1/2]$ on the selected two-branch sector), while on the static spacelike branch the spatial background gradient produces the anisotropic characteristic cone with widened longitudinal velocity $v_\parallel^2 = (P_{,X} + 2XP_{,XX})/P_{,X} \in [2, 3]$ on the selected sector without ghost, gradient, or causal instability on the global temporal foliation (Babichev, Mukhanov & Vikman 2008; cf. Adams et al. 2006).

Variation with respect to the Einstein-frame metric, ϕ , and matter fields gives the Einstein-frame field equations, scalar equation of motion, and matter-frame conservation law.

2.3 Field equations and conservation laws

The field equations below are displayed first in the baseline canonical limit ($P \rightarrow X - V$, $K \rightarrow 1$, $\alpha_{\text{GB}} f(\phi) \mathcal{G} \rightarrow 0$). The general noncanonical completion adopted for the screening, wide-binary, and astrophysical sectors is stated directly alongside them. Varying the action with respect to the Einstein-frame metric, ϕ , and the matter fields yields three sets of equations. The variation displayed in this subsection is the sector-isotropic evaluation of the canonical shorthand metric — exact for the homogeneous background mode and for the nonrelativistic (dust) weak-field source used below. On the lapse-resolved realization of Section 2.2 the inhomogeneous conformal response acts instead through the $U_\mu U_\nu$ channel, so the local u -field couples to $\mathcal{T}^{\mu\nu} U_\mu U_\nu$ — the matter energy density rather than the trace alone — while recovering the identical nonrelativistic source $\nabla \cdot (P_{,X} \nabla \phi) = \rho_* A_{,\phi}$; the homogeneous-mode statement that radiation sources the conformal sector only weakly (through $T \simeq 0$) applies to the isotropic direction, not to the resolved lapse variation.

Einstein-frame field equations

$$G_{\mu\nu} = \frac{1}{M_{\text{Pl}}^2} [T_{\mu\nu}^{(\phi)} + T_{\mu\nu}^{(m)}], \quad (20)$$

with the scalar stress-energy in the baseline canonical limit

$$T_{\mu\nu}^{(\phi)} = \nabla_\mu \phi \nabla_\nu \phi - g_{\mu\nu} \left[\frac{1}{2} (\nabla \phi)^2 + V(\phi) \right]. \quad (21)$$

For the operative noncanonical completion $P(X, \phi)$ with $X = -\frac{1}{2}(\nabla \phi)^2$, the scalar stress-energy tensor is

$$T_{\mu\nu}^{(\phi)} = P_{,X} \nabla_\mu \phi \nabla_\nu \phi + P(X, \phi) g_{\mu\nu}, \quad (22)$$

which reduces identically to the canonical form for $P = X - V(\phi)$.

The Einstein-frame matter stress-energy $T_{\mu\nu}^{(m)}$ is obtained from $S_m[\tilde{g}]$ by functional differentiation with respect to the inverse Einstein-frame metric $g^{\mu\nu}$:

$$T_{\mu\nu}^{(m)} = -\frac{2}{\sqrt{-g}} \frac{\delta S_m}{\delta g^{\mu\nu}} = \frac{\sqrt{-\tilde{g}}}{\sqrt{-g}} \tilde{T}_{\alpha\beta}^{(m)} \frac{\partial \tilde{g}^{\alpha\beta}}{\partial g^{\mu\nu}}, \quad (23)$$

where $\tilde{T}_{\alpha\beta}^{(m)} = -\frac{2}{\sqrt{-\tilde{g}}} \frac{\delta S_m}{\delta \tilde{g}^{\alpha\beta}}$ is the matter-frame stress-energy. For the disformal inverse

$$\tilde{g}^{\mu\nu} = A^{-2} \left[g^{\mu\nu} - \frac{(B/A^2) \partial^\mu \phi \partial^\nu \phi}{1 + (B/A^2)(\partial \phi)^2} \right], \quad (24)$$

the Jacobian $\partial\tilde{g}^{\alpha\beta}/\partial g^{\mu\nu}$ can be evaluated exactly. Writing $Y \equiv g^{\mu\nu}\nabla_\mu\phi\nabla_\nu\phi = -2X$, $D_2 = B/A^2$ and $W = 1 + D_2Y$, so that $\sqrt{-\tilde{g}} = A^4\sqrt{W}\sqrt{-g}$, variation of $S_m[\psi, \tilde{g}]$ with respect to $g^{\mu\nu}$ at fixed $\nabla_\mu\phi$ gives

$$T_{\mu\nu}^{(m)} = A^2\sqrt{W} \left[\tilde{T}_{\mu\nu}^{(m)} - \frac{2D_2}{W} \phi^\alpha \tilde{T}_{\alpha(\mu}^{(m)} \phi_{\nu)} + \frac{D_2^2}{W^2} (\phi^\alpha \phi^\beta \tilde{T}_{\alpha\beta}^{(m)}) \phi_\mu \phi_\nu \right], \quad (25)$$

which reduces to the conformal result $T_{\mu\nu}^{(m)} = A^2\tilde{T}_{\mu\nu}^{(m)}$ at $B = 0$ (indices on $\tilde{T}_{\alpha\beta}^{(m)}$ are lowered with the matter metric $\tilde{g}_{\alpha\beta}$ throughout). Thus the Einstein-frame equations reduce to a scalar-tensor theory with conformally-coupled matter at leading order; disformal corrections enter through the ϕ -contraction terms at $O(B)$ and are suppressed by the same multi-messenger bounds that constrain the light-cone tilt. The exact (untruncated) source would be required in any regime where the volume-preservation condition of Section 8 were met by a large disformal correction, since the small- B expansion is not uniformly valid there; Section 8 shows that no such regime is physically admissible — the reconstruction is excluded by its own null cone — so the untruncated source is needed only in the formal reconstruction test itself, not on the realized background.

Scalar equation of motion

For the scalar equation it is useful to define the matter-frame stress tensor by

$$\tilde{T}^{\mu\nu} \equiv \frac{2}{\sqrt{-\tilde{g}}} \frac{\delta S_m}{\delta \tilde{g}_{\mu\nu}}. \quad (26)$$

This is equivalent to the covariant definition

$$\tilde{T}_{\mu\nu} = -\frac{2}{\sqrt{-\tilde{g}}} \frac{\delta S_m}{\delta \tilde{g}^{\mu\nu}}, \quad (27)$$

with indices raised and lowered using $\tilde{g}_{\mu\nu}$.

The density-weighted tensor is also defined as

$$\mathcal{T}^{\mu\nu} \equiv \frac{\sqrt{-\tilde{g}}}{\sqrt{-g}} \tilde{T}^{\mu\nu}. \quad (28)$$

Varying the matter metric with respect to ϕ gives

$$\delta_\phi \tilde{g}_{\mu\nu} = 2AA_{,\phi} g_{\mu\nu} \delta\phi + B_{,\phi} \nabla_\mu \phi \nabla_\nu \phi \delta\phi + B (\nabla_\mu \delta\phi \nabla_\nu \phi + \nabla_\mu \phi \nabla_\nu \delta\phi). \quad (29)$$

After integrating the derivative terms by parts, the scalar equation can be written as

$$\square\phi - V_{,\phi} = -\mathcal{Q}, \quad (30)$$

where

$$\mathcal{Q} = AA_{,\phi} g_{\mu\nu} \mathcal{T}^{\mu\nu} + \frac{1}{2} B_{,\phi} \mathcal{T}^{\mu\nu} \nabla_\mu \phi \nabla_\nu \phi - \nabla_\mu (B \mathcal{T}^{\mu\nu} \nabla_\nu \phi). \quad (31)$$

Equivalently,

$$\square\phi = V_{,\phi} - AA_{,\phi}g_{\mu\nu}\mathcal{T}^{\mu\nu} - \frac{1}{2}B_{,\phi}\mathcal{T}^{\mu\nu}\nabla_\mu\phi\nabla_\nu\phi + \nabla_\mu(B\mathcal{T}^{\mu\nu}\nabla_\nu\phi). \quad (32)$$

In the conformal limit $B \rightarrow 0$, this reduces to the standard conformally coupled scalar-tensor source equation,

$$\square\phi - V_{,\phi} = -AA_{,\phi}g_{\mu\nu}\mathcal{T}^{\mu\nu}. \quad (33)$$

For the operative noncanonical sector $P(X, \phi)$, variation of the action yields the noncanonical equation of motion

$$\nabla_\mu(P_{,X}\nabla^\mu\phi) + P_{,\phi} = -\mathcal{Q}, \quad (34)$$

which recovers the canonical $\square\phi - V_{,\phi} = -\mathcal{Q}$ form where a canonical kinetic term is restored and $P_{,X} \rightarrow 1$ with $P_{,\phi} \rightarrow -V_{,\phi}$. On the selected two-branch sector $P_{,X} = 1$ is not an asymptotic limit — it is attained only at the isolated value $\xi \simeq 4 \times 10^{-3}$; the weak-gradient environment sits instead on the $k\sqrt{\xi}$ branch. This noncanonical form is the operator whose static limit $\nabla \cdot (P_{,X}\nabla\phi) = \rho_*A_{,\phi}$ derives the screening stiffness and wide-binary response throughout Sections 2.2 and 7.

Equivalently, in terms of the effective scalar coupling

$$\alpha(\phi) \equiv \frac{d \ln A}{d\phi}, \quad (35)$$

the conformal source is proportional to the matter trace. Nonrelativistic matter sources the scalar through $T \simeq -\rho$, while radiation with $T \simeq 0$ weakly sources the conformal sector, as used in the cosmological discussion.

Matter-frame conservation law

$$\tilde{\nabla}_\mu \tilde{T}_{(m)}^{\mu\nu} = 0, \quad (36)$$

which follows from diffeomorphism invariance of $S_m[\tilde{g}]$ and implies that non-gravitational test particles and light follow geodesics of the matter metric $\tilde{g}_{\mu\nu}$. In the Einstein frame, matter and the scalar exchange energy-momentum. Diffeomorphism invariance gives

$$\nabla_\mu T_{(m)}^{\mu\nu} = \mathcal{Q}\nabla^\nu\phi, \quad (37)$$

while the scalar stress tensor satisfies

$$\nabla_\mu T_{(\phi)}^{\mu\nu} = -\mathcal{Q}\nabla^\nu\phi. \quad (38)$$

Therefore the total Einstein-frame stress tensor is conserved:

$$\nabla_\mu (T_{(m)}^{\mu\nu} + T_{(\phi)}^{\mu\nu}) = 0. \quad (39)$$

The matter-frame conservation law remains

$$\tilde{\nabla}_\mu \tilde{T}_{(m)}^{\mu\nu} = 0, \quad (40)$$

because matter is minimally coupled to $\tilde{g}_{\mu\nu}$.

These equations define the EFT structure used throughout the paper. The scalar source $\mathcal{Q}$ displays the leading conformal-disformal matter coupling explicitly.

3. Operational Foundations: Measurement, Simultaneity, and One-Way Light

3.1 What is actually measured

No measurement of c uses null proper time along the photon's worldline; that would be $c = dx/d\tau$ with $d\tau = 0$. Instead, a distance is compared with an elapsed proper time on an observer's clock. For two spatially separated clocks A and B with worldlines γ_A, γ_B and a light path λ from A to B, the measured one-way time t_{AB} is the difference in B's proper time between emission and reception, after a synchronization convention has assigned simultaneity between A and B. Two-way measurements are convention-independent; one-way measurements are not, unless an invariant observable is provided.

3.2 The synchronization problem in a dynamical-time background

Einstein synchronization assumes (i) reciprocity of propagation and (ii) homogeneity of time standards along the path. If the rate $d\tau/dt$ varies spatially or directionally, synchronization by light exchange over extended loops becomes path-dependent. The proper formalism invokes the congruence u_μ of observers (clocks) and the null geodesics k^μ of $\tilde{g}_{\mu\nu}$. Define simultaneity as orthogonality to u_μ (where Frobenius integrability allows it), and define time transport by mapping a proper-time interval at A to B using $\tilde{g}$ -null signals. In GR, the non-closure of such transports arises from rotation of the congruence (vorticity) and spacetime curvature (Sagnac/Shapiro); both can be modeled and removed. In a dynamical-time geometry with disformal couplings, there is an additional, tiny non-exact contribution to time transport that cannot be removed by coordinate choices: a synchronization holonomy.

3.3 A convention-independent observable: synchronization holonomy

The operational observable is not a raw one-way speed and not the integral of a scalar proper-time differential. It is the residual non-closure of synchronization transport around a closed loop after subtracting the GR prediction.

Let $\tilde{\sigma}$ denote the matter-frame synchronization transport one-form induced by $\tilde{g}_{\mu\nu}$ and the chosen clock congruence, and let σ_{GR} denote the corresponding GR one-form including Sagnac, gravitomagnetic / Lense–Thirring, Shapiro delay, gravitational redshift, station motion, clock-scale realization, and reference-frame corrections. The residual holonomy is:

$$H_{\text{resid}}(C) \equiv \oint_C (\tilde{\sigma} - \sigma_{\text{GR}}) = \iint_\Sigma (d\tilde{\sigma} - d\sigma_{\text{GR}}), \quad C = \partial\Sigma. \quad (41)$$

Equivalently, defining $\tilde{F} = d\tilde{\sigma}$ and $F_{\text{GR}} = d\sigma_{\text{GR}}$:

$$H_{\text{resid}}(C) = \iint_\Sigma (\tilde{F} - F_{\text{GR}}). \quad (42)$$

This quantity is invariant under admissible synchronization re-gaugings because the matter-frame connection $\tilde{\sigma}$ and the corresponding GR reference connection σ_{GR} shift by the same exact one-form, leaving the residual connection $\Delta\sigma = \tilde{\sigma} - \sigma_{\text{GR}}$ unchanged. Equivalently, any representative shift by an exact form integrates to zero around a closed loop.

Conformal exactness and vanishing loop holonomy

In the conformal-only subclass ($B = 0$), the scalar contribution to local clock-rate transport is generated by the exact one-form $\omega^{(A)} = d \ln A$. For any closed loop C in a simply connected region where $A(\phi)$ is smooth and single-valued:

$$\oint_C \omega^{(A)} = \oint_C d \ln A = 0. \quad (43)$$

Thus a conformal-only scalar may affect local rates and open-path redshift comparisons, but it cannot by itself generate a closed-loop residual synchronization holonomy. A leading-order nonzero H_{resid} requires residual synchronization curvature $d(\tilde{\sigma} - \sigma_{\text{GR}}) \neq 0$, which in this framework arises from the disformal sector, non-metricity, or other explicitly non-exact transport structure.

This reframes "variable c" claims: the invariant diagnostic is not a raw one-way c, but H_{resid} . A nonzero H_{resid} means simultaneity is not integrable beyond GR; this is what dynamic time does to measurement.

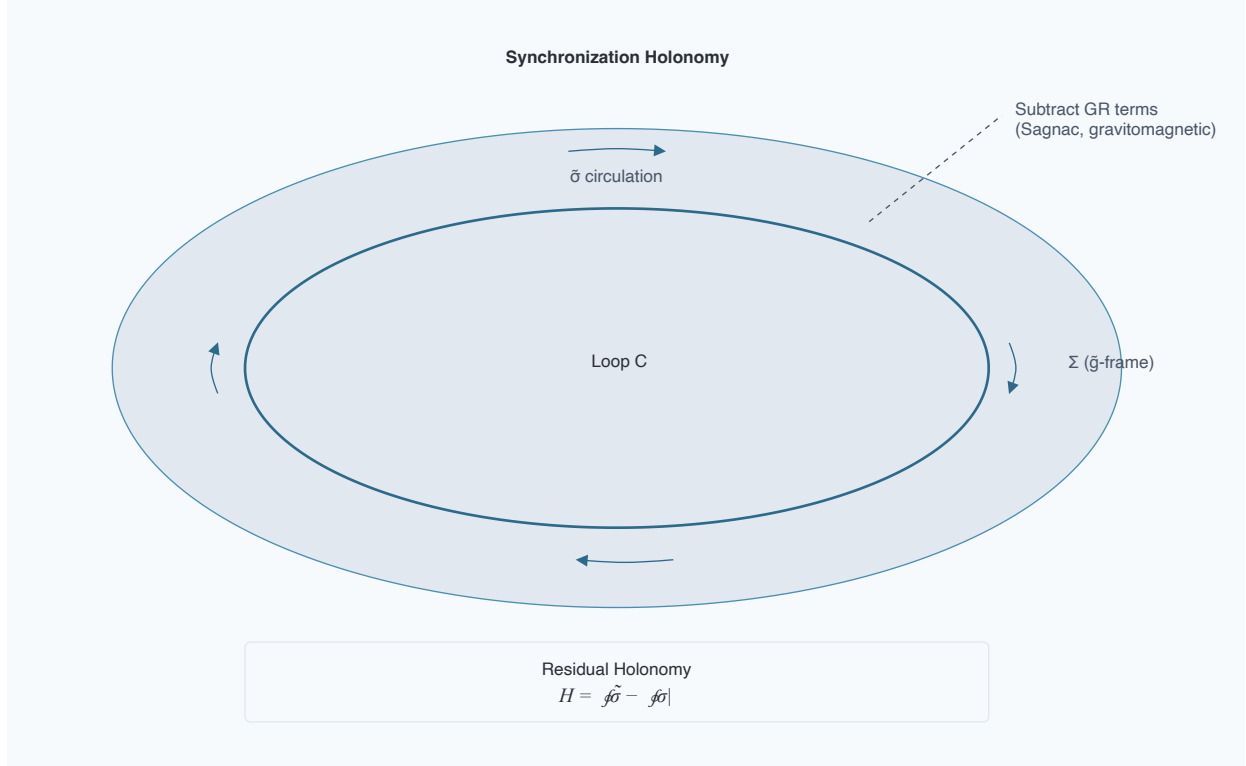


Figure 2. Synchronization holonomy on a spacelike slice in the matter frame. The residual invariant H_{resid} subtracts all GR corrections (Sagnac, gravitomagnetic / Lense–Thirring, Shapiro delay, gravitational redshift, station motion, clock-scale realization, and reference-frame corrections), isolating dynamical-time effects.

4. Disformal Invertibility, Causality, and Hyperbolicity

Invertibility and signature

The inverse of $\tilde{g}_{\mu\nu}$ exists for $A > 0$ and $1 + (B/A^2)(\partial\phi)^2 \neq 0$:

$$\tilde{g}^{\mu\nu} = A^{-2} \left[g^{\mu\nu} - \frac{(B/A^2)\partial^\mu\phi\partial^\nu\phi}{1 + (B/A^2)(\partial\phi)^2} \right]. \quad (44)$$

For Lorentzian signature, require $A > 0$ and $B(\partial\phi)^2 > -A^2$. B is assumed small and gradients bounded in all regimes of interest.

Causality

The matter cone is inside or equal to the gravitational cone when $B \geq 0$ and gradients are modest; no closed causal curves arise for small B . When the observable disformal deformation $\frac{B(\phi)}{A^2(\phi)}(\partial\phi)^2$ is negligible along the relevant late-time propagation paths, gravitational and matter null cones coincide to the required observational accuracy. Laboratory resonator tests independently constrain orientation-dependent components of the same local disformal deformation in the terrestrial environment, while multi-messenger observations strongly constrain its integrated realization along astrophysical propagation paths. These constraints bound the complete disformal deformation on the realized scalar background rather than requiring $B(\phi)$ itself to vanish identically. With B small, any phase differences in propagation are minute and bounded by multi-messenger results.

Hyperbolicity

The canonical scalar equation has a hyperbolic principal operator on a Lorentzian background; $V'' > 0$ supplies positive-mass stability near an equilibrium. In the small-disformal EFT used here the theory is treated perturbatively about that background. On the admissible branch $B \geq 0$ the disformal perfect-fluid principal coefficients are $Z_t = 1 + B(1 + w)\rho/A^2 \geq 1$ and $Z_s = 1 + B(1 - w)\rho/(3A^2) \geq 1$ for $-1 \leq w \leq 1$ and $\rho \geq 0$, so this sector is strongly hyperbolic wherever the matter metric is non-degenerate. The elliptic counterexamples require $B < 0$. The null-cone condition therefore selects $B \geq 0$ as the unconditionally admissible branch: on it the signature condition $B(\partial\phi)^2 > -A^2$ and the hyperbolicity inequalities hold wherever the matter metric is non-degenerate, and the matter cone lies inside or on the gravitational cone. $B < 0$ is not excluded a priori; it carries a pointwise admissibility condition — signature ($|B|(\partial\phi)^2 < A^2$), hyperbolicity ($Z_t, Z_s > 0$), and causality (the matter cone remaining inside the gravitational cone) — evaluated on each realized configuration, and sign-indefinite forms $B(\phi)$ inherit the same condition along the realized profile. The configurations computed to date fail it on the negative branch: the volume-balance disformal reconstruction returns its required $b(\varphi)$ negative and drives $Q = 1 + (B/A^2)(\partial\phi)^2 \rightarrow -1$ — a matter-metric degeneracy with superluminal longitudinal photons along $\nabla\phi$ (Appendix E, R5). The exclusion is therefore conditional rather than axiomatic: any future sign-indefinite realization enters the corpus through this ledger, not through a relaxation of it. The ledger is evaluated numerically on the corpus's realized scalar profiles in step 52. On the GW170817-type galactic profile the signature wall sits 10^{15} above the multimessenger bound and the fluid-hyperbolicity wall $10^{6.5}$ above it, so a negative excursion is formally admissible there far beyond phenomenologically relevant amplitudes; in dense bodies the same fluid wall collapses to $|B_0| \lesssim 0.7$ inside Earth and $\lesssim 2 \times 10^{-16}$ inside a neutron star, because the condition is gradient-independent ($R\mathcal{D} = \rho \text{shape}(u) R_H^2/(M_{\text{Pl}}\hbar c)^2$, a coupling–density bound $|B(\phi)|\rho \lesssim A^2$). In the timelike-gradient drift channel the roles reverse: the negative branch is lapse-safe while the positive branch carries the lapse boundary $u(\varphi) = B(\varphi)\dot{\phi}^2/A^2 < 1$. The relevant bound is realized rather than fiducial: under the adopted clock map $\bar{\varphi} = \ln(1 + z)$, with $\dot{u} = H_T(z) \approx 4\text{--}5 H_0$ under the imported Λ CDM drift and $A \approx 0.22\text{--}0.29$ at the absorber epochs, the ambient lapse cap on the canonical envelope falls to $B_0 \lesssim 0.03$ near $z \approx 3$ — three-to-four orders below the phenomenological requirements ($B_0^{\text{req}} \sim 52$ in the per-length estimate, $\simeq 420$ under the step-63 NFW deprojection) and the conservative multimessenger envelope $B_0 \lesssim 78$. Under the TEP-native drift ($H_T^2/H_0^2 \approx 0.22\text{--}0.44$ on the descent and selected-tracking branches) the cap loosens to $B_0 \lesssim 1.0\text{--}4.5$ and the required ambient suppression relaxes to $G_{\text{ambient}} \lesssim 0.01\text{--}0.06$ at the phenomenological B_0 — the phenomenological amplitudes remain supercritical on the bare ambient by a factor $\sim 30\text{--}50$ under the native rate, so ambient closure is lapse-mandated on either drift. The negative branch is simultaneously bounded at $|B_0| \lesssim 10^{-2}$ by the ambient fluid wall at absorber-epoch densities, a rate-independent wall (step 52; Paper 29, Gates 10-b/10-c). Neither sign can therefore carry the phenomenological amplitude on the bare ambient: ambient closure of the environment-modulated form $B_{\text{eff}} = B(\phi)G(X_{\text{local}})$ is lapse-mandated independently of the absorber-amplitude argument, and the required suppression is consistent with the in-well saturation $G \sim 10^{-3}$ that Gate 10-b infers phenomenologically — the lapse wall and the absorber amplitudes select the same modulated form, while a uniform positive B_0 has no realized window. The step-63 NFW deprojection independently excludes the uniform- B_0 Refsdal carrier ($B_0^{\text{req}} \simeq 420$ against the bound $\lesssim 78$), while the same gated form returns $B_0^{\text{req}} \simeq 0.02$ against a same-convention bound $\sim 10^{10}$ — the modulated coupling leaves that channel viable as well. The dangerous sign is gradient-character selective rather than universal, which is the computed content of the branch statement. The characteristic analysis of the noncanonical completion $P(X)$ is treated separately from the disformal matter-metric analysis and is summarized in §2.2 and Appendix E (step 61); the strong-field black-hole interior in which $|(B/A^2)X|$ is not small is treated in Paper 28. Multimessenger observations strongly constrain the relevant late-time disformal combinations along astrophysical paths, while the realized background solution must independently satisfy the signature condition in other environments. Within the small- B , canonical-scalar EFT regime considered here, no ghost or gradient instability is introduced at leading order. The EFT is valid below the disformal scale M , with higher-dimensional operators suppressed. The specific phenomenological window for the cutoff scale M is bounded from below by the requirement that the EFT remains strictly valid across terrestrial and solar-system density gradients, and from above by the requirement that $B(\phi)$ generates a detectable macroscopic holonomy without violating the $|c_\gamma - c_g|/c$ multi-messenger constraints. These conditions are established within the small- B EFT regime: companion analyses that remain within it, such as the conformal-sector early-universe calculations of TEP-BBN, inherit them directly, while strong-field applications such as the black-hole construction of Paper 28 extend beyond it and must re-establish them on the realized configuration.

5. Local Lorentz Invariance, Proper Time, and the Emergence of c

Proper time

Clocks measure $d\tau^2 = -\tilde{g}_{\mu\nu}dx^\mu dx^\nu/c^2$. In a local lab with small velocities and $\partial_0\phi \ll |\nabla\phi|$, $-\tilde{g}_{00} \approx A(\phi)^2(-g_{00}) - B(\partial_0\phi)^2$, so

$$\frac{d\tilde{\tau}}{d\tau_g} = A(\phi), \quad (45)$$

up to $O(B)$ corrections. This "dynamical time law" rescales all frequency standards locally.

Local c

All small labs measure an invariant c ; the conformal factor rescales both clocks and rulers uniformly, preserving null cones. Thus the empirical fact " c is constant" remains a theorem of the theory at the local level.

Global measures

Global "speeds" involve synchronized endpoints. Because the matter metric depends on the dynamical temporal field, global synchronization can acquire non-integrability when the resulting transport contains a disformal or otherwise non-exact component. That non-integrability—not a local violation of Lorentz invariance—is the source of observable departures.

6. Synchronization in a Dynamical Time: One-Way Light and Holonomy

Operational definitions

Two-way light speed is synchronization-independent and has established c 's local invariance. One-way measures require synchronized clocks at A and B; Einstein synchronization assumes time-orthogonal slices and propagation symmetry. In a dynamical ϕ background, slow clock transport and one-way synchronization are path and history dependent.

Key theorems

Theorem 1 (Conformal null-cone invariance)

For $\tilde{g}_{\mu\nu} = A(\phi)^2 g_{\mu\nu}$, null vectors of $g_{\mu\nu}$ are null for $\tilde{g}_{\mu\nu}$. Maxwell's action is conformally invariant in 4D, so photon trajectories are null with respect to both metrics. Gravitational and electromagnetic waves share null cones when $B = 0$ at late times.

Theorem 2 (Exact direct conformal propagation null)

In the purely conformal limit $B = 0$, the multiplicative conformal factor $A^2(\phi)$ preserves the null cone exactly. A static conformal rescaling therefore produces no direct direction-odd same-path photon-propagation delay:

$$\Delta t_{\text{prop}}^{(A)} = 0. \quad (46)$$

The conformal clock connection is exact, $\omega^{(A)} = d \ln A$, and hence $\oint_C d \ln A = 0$ in a smooth simply connected region. Observable conformal effects remain possible through clock-rate differences, accumulated proper-time histories, and open-path redshift comparisons. Scalar-induced backreaction on $g_{\mu\nu}$, time-dependent geometry, the disformal sector, or another non-exact transport structure are separate channels and are not excluded by this theorem.

Proof sketch. For $\tilde{g}_{\mu\nu} = A^2(\phi) g_{\mu\nu}$ with $B = 0$, a photon null condition $\tilde{g}_{\mu\nu} k^\mu k^\nu = 0$ reduces to $g_{\mu\nu} k^\mu k^\nu = 0$ because $A > 0$. The conformal factor therefore cancels exactly from the null propagation condition and cannot act as a direction-dependent refractive index at fixed $g_{\mu\nu}$; see Appendix A2 for the full derivation. The scalar's backreaction on $g_{\mu\nu}$ can still alter ordinary gravitational lensing and Shapiro delays, which require a solved metric and are not implied by a curl of a screened scalar current.

Synchronization one-form and holonomy

Decompose $\tilde{g}_{\mu\nu}$ in 3+1 form:

$$\tilde{g}_{\mu\nu} dx^\mu dx^\nu = -\tilde{N}^2 dt^2 + \tilde{h}_{ij} (dx^i + \tilde{N}^i dt)(dx^j + \tilde{N}^j dt). \quad (47)$$

Define the coordinate synchronization connection by the threading representative

$$\tilde{\sigma}_i = \frac{\tilde{g}_{0i}}{\tilde{g}_{00}}, \quad (48)$$

up to the overall sign convention adopted for simultaneity transport. In ADM variables, for small shift,

$$\tilde{\sigma}_i \simeq -\frac{\tilde{N}_i}{\tilde{N}^2}. \quad (49)$$

The representative used throughout is the fixed coordinate-time connection $\tilde{\sigma}_i = \tilde{g}_{0i}/\tilde{g}_{00}$ defined above, applied identically to $\tilde{\sigma}$ and σ_{GR} . A proper-time-normalized representative $N\tilde{\sigma}$ is a different loop observable when the lapse varies spatially — $\oint_C N\tilde{\sigma} \neq N \oint_C \tilde{\sigma}$, and under a re-gauging $\tilde{\sigma} \rightarrow \tilde{\sigma} - d\chi$ the shift $N d\chi$ is not exact — so normalization is part of the observable's definition. The operational conversion is specified at link level: each measured one-way desynchronization between neighbouring clocks, $\Delta\tilde{\tau}_{\text{link}}$, is divided by the local matter-frame lapse $\tilde{N}$ to recover the connection element $\tilde{\sigma}_i dx^i = \Delta\tilde{\tau}_{\text{link}}/\tilde{N}$, and summing over the loop reconstructs $\oint_C \tilde{\sigma}$; the identical reduction applied to the GR model yields H_{resid} . Appendix A3 supplies the connection's transformation properties and leading disformal contribution; the timestamp reduction follows from the fixed convention above rather than from an additional assumption. For a closed spatial loop C , the raw loop integral is

$$H = \oint_C \tilde{\sigma}, \quad (50)$$

but the physical TEP observable is the GR-subtracted residual

$$H_{\text{resid}}(C) = \oint_C (\tilde{\sigma} - \sigma_{\text{GR}}) = \iint_{\Sigma} (d\tilde{\sigma} - d\sigma_{\text{GR}}), \quad C = \partial\Sigma. \quad (51)$$

In GR with stationary spacetimes, the raw holonomy reproduces the Sagnac/gravito-magnetic effect; these known contributions are subtracted using geodesy and ephemerides. The residual holonomy beyond GR is therefore

$$H_{\text{resid}}(C) = \iint_{\Sigma} (d\tilde{\sigma} - d\sigma_{\text{GR}}), \quad C = \partial\Sigma, \quad (52)$$

where σ_{GR} includes the standard Sagnac, gravitomagnetic/Lense–Thirring, Shapiro, gravitational-redshift, station-motion, clock-scale, and reference-frame contributions. This residual vanishes in SR/GR with $B = 0$ and stationary A ; it becomes non-zero only where the transport produces a residual circulation, requiring the drift rate's gradient to be misaligned with the field gradient — the disformal-curvature condition $d(\delta\tilde{\sigma}) = -(B/A^2) d(\dot{\phi}/N^2) \wedge d\phi$ of §7. The Temporal Topology is thereby expressed as a measurable geometric consequence. Because $\tilde{\sigma}_i = \tilde{g}_{0i}/\tilde{g}_{00}$ is a ratio, the conformal factor cancels from it identically, so a time-dependent A cannot generate synchronization holonomy; the residual is generically nonzero only with disformal corrections ($B \neq 0$) or other non-exact transport. Path-dependent accumulated proper time under a time-dependent A is a distinct observable, the clock anholonomy of Section 10B. Configurations in which C does not bound a smooth surface — non-simply-connected transport, or a connection that is locally closed but not globally exact — are not described by this Stokes expression and are treated as a separate topological case in Appendix A3.

Gauge and protocol invariance

$\tilde{\sigma}$ and σ_{GR} are synchronization-connection representatives for the same physical clock network and the same loop, evaluated in the matter-frame model and the corresponding GR reference model respectively. A synchronization re-gauging $t \rightarrow t + \chi(x^i)$ shifts both representatives by the same exact one-form. Therefore the GR-subtracted connection

$$\Delta\sigma = \tilde{\sigma} - \sigma_{\text{GR}} \quad (53)$$

and its closed-loop integral

$$H_{\text{resid}}(C) = \oint_C \Delta\sigma \quad (54)$$

are invariant under admissible synchronization changes. This addresses the critique that holonomy is conventional: the observable is the residual loop class of $\Delta\sigma$, not the exact part of any raw one-way synchronization convention.

Disformal corrections to $\tilde{\sigma}$

For small B and modest $\partial\phi$,

$$\tilde{N} \approx AN \left[1 - \frac{B}{2A^2 N^2} (n \cdot \partial\phi)^2 \right], \quad \tilde{N}_i \approx A \left[N_i + \frac{B}{A^2} (\partial_i \phi) (n \cdot \partial\phi) \right], \quad (55)$$

with n^μ the unit normal to slices. Then $\delta\tilde{\sigma}$ denotes the leading disformal correction to the chosen synchronization representative. Its covariant clock-congruence form is derived in Appendix A3; in a hypersurface-orthogonal $3+1$ slicing it reduces, up to lapse/shift convention and overall sign, to the expression proportional to

$$-\frac{B}{A^2 N} (\partial_i \phi) (n \cdot \partial\phi) dx^i. \quad (56)$$

At leading order beyond the GR-subtracted reference model,

$$d(\Delta\sigma) = d(\tilde{\sigma} - \sigma_{\text{GR}}) \supset d(\delta\tilde{\sigma}), \quad (57)$$

where the Δ indicates the residual beyond GR. Time dependence and a spatial gradient permit, but do not guarantee, non-vanishing curl: on a fixed spatial slice the leading representative is $\delta\tilde{\sigma} = -C d_3\phi$, with $C = (B/A^2)(u \cdot \nabla\phi)$ in the local clock frame (or the corresponding lapse-weighted expression in the stated slicing), hence $d_3(\delta\tilde{\sigma}) = -d_3 C \wedge d_3\phi$. A spatially uniform drift or any $C = C(\phi)$ gives zero circulation. In particular B/A^2 depends on ϕ alone in the stated action and contributes no separate wedge term; the spatial variation of the drift/lapse relative to $\nabla\phi$ is the operative condition. This is distinct from $d[P_{,X}d\phi]$, the curl of the scalar kinetic flux: neither that flux nor a phenomenological $S_\Sigma d\phi$ is the photon synchronization connection.

7. Screening, PPN, Equivalence Principle, and Disformal Bounds

Screening

Screening in TEP is described as suppression of the locally observable Temporal Shear/source-charge sector, not as a commitment to a specific chameleon, Vainshtein, Galileon, DBI, or symmetron microphysics. Those mechanisms may be studied as candidate completions. In the effective theory used here, screening is expressed through the conformal factor $\ln A(\phi)$, its gradient Σ_μ , and its covariance C_A . Source structure, environmental state, and boundary conditions suppress the locally active shear sector in screened regimes.

The saturation scale ρ_T denotes the Temporal Topology saturation scale. It is not a local on/off condition of the form $\rho > \rho_T \Rightarrow \text{GR}$ and $\rho < \rho_T \Rightarrow \text{active}$. Recovery of GR in local tests is controlled by suppression of the observable shear/source-charge sector, $\Sigma_\mu^{\text{obs}} = \mathcal{S}_\Sigma(\mathcal{E})\Sigma_\mu$ with $\mathcal{S}_\Sigma \rightarrow 0$ in screened regimes, where $\mathcal{E}$ includes source structure, environment, boundary conditions, and density.

Screening is not a single density switch. It is an environmental suppression operator $\mathcal{S}_\Sigma(\mathcal{E})$ whose observable projection depends on scale. The environmental state $\mathcal{E}$ includes: ambient density ρ , gravitational compactness Φ/c^2 , density gradients $\nabla\rho$, potential gradients $\nabla\Phi$, proximity to field sources, coherence volume, boundary geometry, and asymptotic horizon proximity. Each domain uses a different projection of $\mathcal{E}$:

- **GNSS/clock:** clock-amplitude (static conformal-depth) projection $S_A^{(\oplus)} \approx 0.65$ (0.43–0.88 across the ρ_T band) of the conformal time field; the time-dependent spatial covariance is carried by C_A .
- **UCD/galaxy scales:** mass-radius-density saturation projection through the geometric scale $R_T(M)$.
- **NIST/laboratory G:** lab-scale geophysical column projection of $S_\Sigma(\mathcal{E})$.
- **MSP pulsars:** cluster-potential response with stellar/environmental transfer.
- **Cepheids:** galactic-potential clock-bias response.
- **JWST/high-z:** halo-potential response transferred from Cepheid prior.
- **Wide binaries:** weak-field recovery / low-acceleration environmental un-screening.
- **Flyby:** clock-sector reduction artefact in clock-carrying links (Section 2.2); the Earth-vicinity shear is pairwise-screened and carries no flyby shear signal, and the coherent two-way class of the published catalogue carries no clock term — the artefact is a prediction for one-way/non-coherent radio science.
- **LLR:** compactness-dependent Earth/Moon differential screening.
- **LHC:** proximity-saturated hadronic coherence-volume screening.
- **SPIN/QF/KIN:** subatomic proximity/topological-core screening as microscopic projection of $S_\Sigma(\mathcal{E})$.
- **C0/HC/TH:** temporal-horizon asymptotic transport and late-time conformal acoustic equivalence.

These projections are not interchangeable. Each is calibrated against the environmental variables active in its domain, and evaluating a projection outside the regime where its governing variable dominates yields screening factors that are physically meaningless, as the omitted terms can exceed the retained ones by many orders of magnitude.

The local and cosmological screening responses form a continuous nested hierarchy, not two independent regimes separated by a boundary. The temporal field varies both spatially and temporally: the rate of time differs from place to place, and at any given location it also evolves over time. The cosmological temporal background — the ambient clock-rate field $A(\phi_\infty)$ — is itself spatially varying, with gradients across large-scale structure that can differ substantially between cosmic environments, and temporally evolving within its bounded contrast. This evolution is to be distinguished from the secular cosmological drift, which is sector-asymmetric: the drift rate H_{drift} is carried by the matter-hosting field values sourced through $\nabla^2\phi = V_{,\phi} + \rho_* A_{,\phi}$, while the unsourced void sector relaxes toward the contemporaneous ambient configuration with excursions bounded by $|\delta u| \lesssim 10^{-3}$ – 10^{-2} at every epoch (Section 8). The ambient's "temporal evolution" is therefore variation within the contrast band, not carriage of the secular drift — a distinction that fixes which field components enter the loop-holonomy kernel of Section 10A. Within this cosmological baseline, local environmental screening produces additional spatial fluctuations in the observable clock rate and Temporal Shear, smaller in amplitude and varying across shorter scales, and these local fluctuations themselves evolve as the local environment and the cosmological background evolve. The local response is defined relative to the cosmological baseline at the corresponding epoch, not in isolation from it. Both layers are dynamical and continuous in space and time; neither constitutes a discrete transition. The environmental state vector $\mathcal{E}$ therefore carries information at multiple nested scales simultaneously: the cosmological ambient field, the local environmental perturbation, and their coupling, all evaluated at the relevant cosmic epoch. The structure is analogous to temperature in a room: local temperature fluctuates from point to point within the room, but is also defined relative to the external temperature, which itself varies more radically between regions, and all of these temperatures change over time — the room cools at night, the outside temperature shifts with seasons. The temporal field exhibits the same nested character in both dimensions — local clock-rate fluctuations sit within a cosmological time-rate background, both vary continuously across space, and both evolve continuously over time.

The nested structure is quantitative, not merely schematic. Solving the radial field equation for each level of the hierarchy with the containing environment's field as the asymptotic condition — a single continuous profile $\phi_{\text{total}} = \phi_{\text{env}} + \delta\phi$, in which the conformal nonlinearity acts on the total field and the perturbation decays to the ambient value rather than to zero — yields the following nested-hierarchy decomposition (Appendix E, R1). The galactic field at the solar circle is $\phi_{\text{gal}}(8 \text{ kpc}) \simeq 2.8 \times 10^{-7}$ (1.4 – 5.7×10^{-7} across galactic model variants, consistent with the independent circular-velocity estimate $(v_c/c)^2 \simeq 5.4 \times 10^{-7}$), while the Sun's own perturbation at 1 AU is only 2.0×10^{-8} : the ambient field exceeds the solar contribution beyond $\sim 15 R_\odot \approx 0.07 \text{ AU}$, in the $V = 0$ baseline the ambient-to-perturbation ratio is $\sim 9 \times 10^4$ at the wide-binary separation (2646 AU), rising to $\sim 10^7$ across the stellar population — the binary is embedded almost entirely in the galactic field. At the terrestrial surface the decomposition is approximately 93% galactic, 6.5% solar, and 0.5% terrestrial: a local clock measures a small perturbation on a much larger ambient baseline, and because the ambient component is common-mode it cancels in local comparisons. For the same reason the Cassini bound is intrinsically local: it constrains the Sun's gradient perturbation $S_\Sigma^{(\odot)}$, while the ambient galactic field carries negligible gradient over AU scales and drops out of the observable. Under the nested two-body kinetic operator the pairwise shear at the conjunction separation is suppressed to $\mathcal{R}(1.6 R_\odot) \approx 1 \times 10^{-23}$ — orders of magnitude deeper than required — while the Cassini bound itself constrains the single-body exterior source charge, $S_\Sigma^{(\odot)} \lesssim 1.15 \times 10^{-5}$ (5.8×10^{-6} on the isotropic benchmark), which the adopted Solar-System source-charge convention $S_\Sigma^{(\odot)} \sim 2 \times 10^{-6}$ satisfies comfortably (consistent with the kinetic completion of Section 2, whose static-branch operator reproduces the corpus screening values at zero free parameters; the exact single-source Cassini observable is a projection of the solved solar profile — the constant-charge expression retained here is the weak-field benchmark shorthand, not the output of a dedicated single-body extraction). The baseline itself is not uniform: the ambient clock rate differs by $\Delta \ln A \simeq 2.2 \times 10^{-7}$ between the solar circle and the galactic halo, so the proper-time field is genuinely position-dependent across the galaxy — one continuous multi-scale profile with no boundaries between levels. The nested field hierarchy has two complementary properties: the field value at any point is dominated by the largest enclosing structure

(Galaxy, then Sun, then Earth), while the field gradient is dominated by the nearest mass. This gives the clock/shear split its physical content: clock rates are set by the whole nested hierarchy, while the local Temporal Shear is set by the nearest body's gradient.

The parameter $\rho_T \approx 20 \text{ g/cm}^3$ is a macroscopic phenomenological saturation scale for the scalar response. It is not a universal microscopic density cutoff, a binary screened/unscreened switch, or automatically applicable to quantum cores without a transfer map. For quantum and accelerator domains, the microscopic topological-core regulator is a proximity/coherence-volume projection of $\mathcal{S}_\Sigma(\mathcal{E})$, not literal bulk density.

Temporal Topology and Temporal Shear: Canonical Formulation

The screening ontology is organized through a sector dictionary. The Temporal Shear is defined as the gradient of the conformal factor:

$$\Sigma_\mu \equiv \nabla_\mu \ln A(\phi) = \frac{\partial \ln A}{\partial \phi} \nabla_\mu \phi = \frac{\alpha(\varphi)}{M_{\text{Pl}}} \nabla_\mu \phi, \quad (58)$$

where $\alpha(\varphi) \equiv d(\ln A)/d\varphi$ is the dimensionless conformal coupling strength, and $\varphi \equiv \phi/M_{\text{Pl}}$. For compactness one may write $\Theta \equiv \ln A$, but the canonical series notation remains $\ln A$, $\Sigma_\mu = \nabla_\mu \ln A$, and C_A .

The observable Temporal Shear is suppressed by the environmental screening operator $\mathcal{S}_\Sigma(\mathcal{E})$:

$$\Sigma_\mu^{\text{obs}} = \mathcal{S}_\Sigma(\mathcal{E}) \nabla_\mu \ln A(\phi), \quad (59)$$

where the environmental state is

$$\mathcal{E} = \{\rho, \Phi/c^2, \nabla\rho, \nabla\Phi, \text{compactness}, R_T(M), \text{proximity}, T, z, \text{boundary geometry}, \text{coherence volume}\}. \quad (60)$$

The common environmental state $\mathcal{E}$ organizes these domain-specific observable projections; the projections themselves need not be numerically identical.

The Temporal Topology correlation function $C_A(x, x')$ characterizes correlations of conformal-factor fluctuations:

$$C_A(x, x') \equiv \langle \delta \ln A(x) \delta \ln A(x') \rangle. \quad (61)$$

It is measured through clock/covariance data. Because $\Sigma_\mu = \nabla_\mu \ln A$, Temporal Topology and Temporal Shear are not independent fields: C_A describes spatial correlations of the field value, while Temporal Shear describes its gradient structure.

The temporal correlation length λ_T is the characteristic scale extracted from $C_A(x, x')$ in covariance measurements, not a derived algebraic combination of local fields.

The temporal saturation scale ρ_T is the characteristic scale at which Temporal Topology effects saturate in screening; it is a property of the theory's non-linear regime, not a local temporal energy density.

Finally, the observable response of any measurement channel X is parameterized by response coefficients κ_X :

$$\Delta O_X = \kappa_X \cdot \mathcal{S}_X(\mathcal{E}) \cdot \mathcal{F}_X[\Delta \ln A, \Sigma_\mu, C_A; \Phi, \rho, z], \quad (62)$$

where κ_X is an observable response coefficient for channel X , not the microscopic conformal coupling β_A and not a PPN coupling. The locally active PPN coupling is suppressed by the environmental/source screening factor $\mathcal{S}_\Sigma(\mathcal{E})$ and should not be confused with channel response coefficients κ_X .

Phantom-mass amplitude. Temporal Shear affects matter dynamics ($\Phi_{\text{dyn}} = \Phi_N + c^2 \beta_A u_{\text{grav}}$), whereas on the isotropic-conformal benchmark ($\tilde{g}_{\mu\nu} = A^2(\phi) g_{\mu\nu}$, where spatial rulers stretch alongside clocks) the conformal factor adds no direct null-ray deflection at fixed $g_{\mu\nu}$, and under the canonical unified unstretched-space metric ($\tilde{\gamma}_{ij} = \gamma_{ij}$ at fixed epoch $A_{\text{sp}} = 1$; Section 2.2, Step 80) the temporal lapse refracts null rays at half the GR potential weight ($\Phi_{\text{lens}} = \frac{1}{2}(\Phi_{\text{dyn}} + \Psi_{\text{sp}}) = \Phi_N + \frac{1}{2} c^2 \beta_A u_{\text{grav}}$). For spherical

weak-field mass inference at a matched radius, with scalar backreaction negligible and the same mass normalization in both channels, the dynamical-to-baryonic mass ratio (equivalently the isotropic-conformal dynamical-to-lensing ratio) is

$$\begin{aligned} \frac{M_{\text{dyn}}(r)}{M_{\text{bar}}(r)} &= 1 + \frac{a_\phi(r)}{a_N(r)} \equiv 1 + 2\beta_A^2 \mathcal{R}_{\text{dyn}}(r), \\ \frac{M_{\text{lens}}^{\text{GR}}(r)}{M_{\text{dyn}}(r)} &= \frac{1 + \beta_A^2 \mathcal{R}_{\text{dyn}}(r)}{1 + 2\beta_A^2 \mathcal{R}_{\text{dyn}}(r)} \quad (\text{unstretched-space direct refraction}). \end{aligned} \quad (63)$$

Here $\mathcal{R}_{\text{dyn}}$ denotes the response extracted from the existing scalar solution and tracer dynamics, not another coupling or screening law. For an unscreened test probe, it reduces to the solved source-gradient ratio S_Σ ; finite-body and pairwise approximations must retain their stated source, ambient and response assumptions. In particular, the nested benchmark $\mathcal{R}(s) = S_\Sigma(X_{\text{env}})^2 y(s)$ is not a universal lens-aperture prescription. The PPN notation below remains $\alpha_{\text{eff}} = \alpha_0 S_\Sigma$, with $\alpha_0 = \sqrt{2}\beta_A$; its product $\alpha_0 \alpha_{\text{eff}}$ must not be relabelled as α_{eff}^2 . Stellar-orbit weighting and lens-model refitting determine how the dynamical excess enters a measured aperture or a time-delay inference (Papers 4, 5, 19).

Amplitude adequacy at galactic scales. On the superseded unit-term kinetic candidate, with $\beta_A = -1$, the conformal-shear enhancement saturates at $M_{\text{dyn}}/M_{\text{lens}} \rightarrow 1 + \alpha_0^2 = 1 + 2\beta_A^2 = 3$ in the fully unscreened limit ($S_\Sigma \rightarrow 1$). Galaxy-outskirt mass discrepancies are measured at factors of 5–10 in extreme cases, so the conformal ceiling does not by itself carry the full dynamical anomaly. For the isolated, potential-negligible weak-field branch of $P = X - V + X|X|/\Lambda_X^4$, $P_{,X} \rightarrow 1$ at small gradients, so its exterior recovery returns to an inverse-square scalar force rather than an unbounded enhancement — precisely the Keplerian-tail failure for which that candidate is rejected. This ceiling is a property of the rejected baseline, not of the selected kinetic sector.

Selected kinetic completion. The flat-tail branch is the promoted sector of the master action, not an alternative realization: the master-sector admissibility scan (Appendix E, step 54; TEP/closure/) finds $P_{,X}(\xi) = k\sqrt{\xi} + 2\xi$, with $\xi = |X|/\Lambda_X^4$, to be the unique minimal completion within the surveyed power-law family — the $p = 1/2$ tail exponent is uniquely selected by the flat-asymptote condition, and the retained unit term of any $1 + 2\xi$ or $1 + k\sqrt{\xi} + 2\xi$ form restores the Keplerian tail and is rejected. In its low-gradient, potential-negligible spherical limit, flux conservation gives $\phi' \propto 1/r$ and hence $g_{\text{obs}}^2 \simeq a_{\text{eff}} g_{\text{bar}}$ and $v_{\text{flat}}^4 = G M_b a_{\text{eff}}$. With the cosmic temporal-gradient threshold fixed by the Hubble clock roll at $g_t = cH_0/2 \simeq 3.40 \times 10^{-10} \text{ m s}^{-2}$ ($H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$) and the DEF coupling normalization $\alpha_0 = \sqrt{2}\beta_A = -\sqrt{2}$, the natural two-branch crossover $k = 16$ ($\xi_* = (k/2)^2 = 64$) yields $a_{\text{eff}} = 4\sqrt{2} g_t/k = cH_0/(4\sqrt{2}) = 1.202 \times 10^{-10} \text{ m s}^{-2}$ ($k = 4\sqrt{2} g_t/a_0 \simeq 16.03$ at the canonical $a_0 = 1.20 \times 10^{-10} \text{ m s}^{-2}$), deriving Milgrom's $a_0 \sim cH_0$ coincidence directly from the cosmological time field while leaving zero per-system free parameters across all downstream regimes. Data select this sector across domains where non-relativistic MOND and relativistic TeVeS fail: on the corrected ambient/propagator semantics the wide-binary joint test passes it at 0.44σ on the saturation amplitude ($\alpha_{\text{sat}} = 0.371$; derived identity $4\sqrt{2}/k \simeq 0.353$) and 1.69σ on the transition scale ($R_s = 2,646 \pm 182 \text{ AU}$), while the unit-term baseline and the exponential-interpolation candidate are excluded at $\sim 30\sigma$ on amplitude; under the same sector ($P_{,X} = \epsilon_{\text{reg}} + k\sqrt{\xi} + 2\xi$ with zero-gradient regulator $\epsilon_{\text{reg}} = 10^{-3}$ and $k_* = 16.03$ calibrated to a_0), the SPARC radial-acceleration fit (Paper 6, Steps 10, 13) under the action-derived additive force law $g_{\text{obs}} = g_N + a_\phi$ returns RMS 0.2185 dex at $\Upsilon_d = 0.5$ and 0.2004 dex at $\Upsilon_d = 0.35$ — matching the empirical MOND interpolating function (0.1989 dex) at $\Upsilon_d = 0.35$ and outperforming the unit-term baseline (0.2812 dex) by $> 60 \text{ mdex}$ (while the phenomenological quadrature comparator $\sqrt{g_N^2 + a_\phi^2}$ gives 0.1974 dex at $\Upsilon_d = 0.5$ with $k_{\text{fit}} = 15.78$ and outer-edge BTFR median $v_{\text{obs}}/v_{\text{pred}} = 1.0109$). All Solar-System benchmarks sit on the $\xi \gg \xi_*$ quadratic branch ($|\gamma_{\text{PPN}} - 1|_{1.6 R_\odot} = 4.32 \times 10^{-8} \ll 2.3 \times 10^{-5}$; ray-integrated Cassini Doppler $|\gamma_{\text{PPN}} - 1|_{\text{Doppler}} = 9.01 \times 10^{-8}$ and differential Shapiro $|\gamma_{\text{PPN}} - 1|_{\text{Shapiro}} = 3.74 \times 10^{-7} \ll 2.3 \times 10^{-5}$; Step 80) and have zero dependence on the bulk-matter saturation proxy ρ_T .

For a matched spherical radius in the potential-negligible deep-tail limit, if lensing were evaluated under isotropic conformal rescaling $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu}$ (where space stretches alongside time so $A^2(\phi)$ cancels out of null rays), the low-gradient branch would give a conditional dynamical-to-baryonic-lensing ratio $M_{\text{dyn}}/M_{\text{lens}} \simeq g_{\text{obs}}/g_{\text{bar}} \simeq \sqrt{a_{\text{eff}}/g_{\text{bar}}}$ (~ 10 at $g_{\text{bar}} = 1.2 \times 10^{-12} \text{ m s}^{-2}$) and leave only the Planck-suppressed scalar stress tensor ($\kappa_\phi \simeq 6.5 \times 10^{-6}$; Paper 19, Step 64). Under the canonical unified matter metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ ($U_\mu \equiv -\nabla_\mu \bar{\phi}/\sqrt{2\bar{X}}$) — the (3 + 1) ADM realization of TEP's ontology in which the spacetime lapse rescales as $N_{\text{TEP}}(\mathbf{x}) = A_{\text{loc}}(u_{\text{grav}}(\mathbf{x}))N_{\text{GR}}(\mathbf{x})$ along the cosmic temporal flow while at a fixed cosmic epoch ($A_{\text{sp}}(t_0) = 1$) the spatial 3-metric $\tilde{\gamma}_{ij} = \gamma_{ij} = (1 - 2\Phi_N/c^2)\delta_{ij}$ remains unstretched — intermediate clock rates $A_{\text{loc}}(u_{\text{grav}}(\mathbf{x}))$ refract null rays along the line of sight via $n(x) \simeq 1 - 2\Phi_N(x)/c^2 - \beta_A u_{\text{grav}}(x)$. Algebraically, $-(A_{\text{loc}}^2 - 1)U_\mu U_\nu = \frac{1 - A_{\text{loc}}^2}{2\bar{X}} \nabla_\mu \bar{\phi} \nabla_\nu \bar{\phi}$ has the tensor form of a longitudinal disformal shift along the cosmic temporal gradient; critically, however, this lapse rescaling is not a photon-only disformal coupling at fixed Einstein-frame tensor cone (which would split photon and gravitational-wave arrival times by $\Delta t \sim \int |\beta_A| u dl/c \sim 10^7 \text{ s}$ across Galactic and host haloes, the dark-matter-emulator exclusion of Boran et al. 2018, and invert the longitudinal sign in voids where $A > 1$). Because proper time $d\tilde{t} = A_{\text{loc}}(u_{\text{grav}}(\mathbf{x})) dt$ and conformal propagation time $d\eta = dt/A_{\text{sp}}(t, \mathbf{x})$ govern the shared ADM foliation itself, varying the spatially covariant ADM/DHOST gravitational action $S_{\text{grav}} = \frac{1}{2} M_{\text{Pl}}^2 \int d^3x dt \sqrt{\gamma} N_{\text{GR}} [R_{\text{scalar}}^{(3)}(\gamma) + A_{\text{sp}}^{-1} R_{\text{TT}}^{(3)}(\gamma) + \tilde{K}_{ij} \tilde{K}^{ij} - \tilde{K}^2]$ ($\delta S_{\text{grav}}/\delta u_{\text{grav}} \equiv 0$ and $\delta S_{\text{grav}}/\delta A_{\text{sp}} \equiv 0$ in

the quasistatic limit $K_{ij} \rightarrow 0$, preserving the Newtonian Poisson and scalar source equations without Jordan-frame degeneracy; $\tilde{K}_{ij} = A_{\text{sp}}^{1/2} (2N_{\text{TEP}} c)^{-1} \partial_t \gamma_{ij}$; Section 2.2, Step 80) with respect to transverse-traceless tensor perturbations h_{ij}^{TT} of γ_{ij} and varying $S_{\text{EM}}[\tilde{g}]$ with respect to electromagnetic waves A_i^T yields the identical quadratic Lagrangian structure $\propto \sqrt{\gamma} N_{\text{GR}} A_{\text{sp}} [(N_{\text{TEP}} c)^{-2} (\partial_t \psi)^2 - A_{\text{sp}}^{-2} \gamma^{ij} \partial_i \psi \partial_j \psi]$ and shared principal wave operator $\square_{\text{TEP}} = -(N_{\text{TEP}} c)^{-2} \partial_t^2 + A_{\text{sp}}^{-2} \gamma^{ij} \partial_i \partial_j$. Both wave sectors therefore share the exact null cone $ds_{\text{TEP}}^2 = -N_{\text{TEP}}^2(\mathbf{x}) c^2 dt^2 + A_{\text{sp}}^2(t, \mathbf{x}) \gamma_{ij}(\mathbf{x}) dx^i dx^j = 0$ and the identical refractive index $n(x)$ across wells, voids, and cosmic epochs alike, preserving $c_{\text{GW}}(t, \mathbf{x}) = c_\gamma(t, \mathbf{x}) = c N_{\text{TEP}}(\mathbf{x}) / A_{\text{sp}}(t, \mathbf{x})$ and $\Delta t_{\gamma\text{-GW}} = 0$ identically along the GW170817 sightline while supplying the non-baryonic optical deflection across galaxies, clusters (Paper 4, Step 02), strong-lensing delays (Paper 19, Step 64), and CMB lensing (Paper 18, Step 21) from baryons alone and satisfying Solar-System Shapiro bounds via quadratic-branch screening. Since $P_{,X} = k\sqrt{\xi} + 2\xi \rightarrow 0$ as $\xi \rightarrow 0$, the physical ambient floor ($\xi_{\text{env}} \simeq 0.32\text{--}0.52$) together with a small canonical regulator $\epsilon \lesssim 0.1$ at isolated saddle points keeps the operator strictly elliptic at zero data cost; uniqueness across the wider $K(X)$ class remains open.

Universal transfer map ($\beta_A \rightarrow \kappa_X$)

The transfer map translates the microscopic coupling $\beta_A = -1.0$ into domain-specific observable response coefficients (κ_X). Channel-specific response coefficients are observable projections of the universal conformal sector, with $\kappa_X = |\beta_A| S_X(\mathcal{E}_X) \Gamma_X$. They encode the channel geometry and environmental response and are distinct from the frozen microscopic coupling $\beta_A = -1$:

Observable channel coefficients are defined as positive response magnitudes

$$\kappa_X \equiv |\beta_A| S_X(\mathcal{E}_X) \Gamma_X. \quad (64)$$

They are not the bare coupling. S_X is the response projection appropriate to the channel: S_A labels static conformal depth, while time-dependent clock/covariance data require the fluctuation transfer carried by C_A and the measurement model. Source-gradient and dynamical responses are expressed through S_Σ under their specified geometry. J0437's phase-closure channel tests non-exact transport, not a static S_A attenuation. $\mathcal{E}_X$ is the environmental state evaluated for the target channel. Γ_X is a geometric/kinematic projector — a known function of the channel geometry that converts the screened field excursion into the observable's native response. The projectors for the primary channels are derived and tabulated below (Appendix E, R12): the GNSS covariance channel is quadratic in the coupling, $\Gamma_{\text{GNSS}} = |\beta_A|$, with the fluctuation spectrum and correlation scale $\lambda_T \approx R_T$ carried by the channel functional $\mathcal{F}_X$ rather than the projector; the Cepheid and galactic channels carry the distance-to-modulus magnitude conversion $\Gamma_\mu = 5/\ln 10$ (distinct from the Leavitt period-to-magnitude projector $\Gamma_{\text{PL}} = -b/\ln 10$ used by the Papers 11–12 ladder-level slope), the millisecond-pulsar channel the direct proper-time projection $\Gamma_{\text{MSP}} = 1$, and $\Gamma_{\text{LLR}} = 1$ records the unit range normalization. The $S_\Sigma(g)$ factor belongs to the R11 force benchmark; it is not the clock-to-range transfer for a passive reflector or the onboard-clock response of a flyby link. On the selected two-branch sector the wide-binary saturation amplitude follows from the derived flux identity $\Gamma_{\text{WB}} = 4\sqrt{2}/k \simeq 0.353$, and the propagator-plus-vertex reading predicts $\alpha_{\text{sat}} = 0.371$, passing the corrected zero-free-parameter joint test against the observed 0.366 ± 0.012 at 0.44σ (Step 56/020).

Canonical notation registry. The corpus uses a small fixed symbol set, and the same physical scale is not re-lettered between papers. λ_T is the clock/covariance correlation length — the characteristic decay scale of $C_A(x, x')$; its terrestrial realization is the GNSS-measured covariance length L_c , the instrument value of λ_T rather than a separate parameter. L_c is estimator- and product-dependent — $\approx 3.2 \times 10^3$ km in the isotropic estimator and 4.2×10^3 km in the directional cross-sector dispersion (Paper 2), 1.9×10^3 km in the 1-year MGEX multi-constellation window (Paper 14, where short-arc detrending acts as a spatial/temporal high-pass filter), and $\gtrsim 0.7\text{--}1.1 \times 10^3$ km as a raw-SPP pseudorange code-noise lower bound (Paper 3) — and the identification $\lambda_T \approx R_T(M_\oplus)$ is anchored on the 25-year phase-coherent directional-dispersion value, which coincides with $R_T(M_\oplus) = 4146$ km ($\rho_T = 20 \pm 7$ g cm $^{-3}$ inter-center, $[8, 70]$ g cm $^{-3}$ window envelope; Paper 6) and is independently cross-validated at the extragalactic scale by inverting the SH0ES 37-host Cepheid P^2 -carrier fit at the unit-transport benchmark $\lambda_0 = 1$ (with bare coupling $|\beta_A| = 1$), which recovers $\rho_T^{(\text{Cepheid})} = 19.91 \pm 8.02$ g cm $^{-3}$ (Paper 11, Step 62). $R_T(M) = (3M/4\pi\rho_T)^{1/3}$ is the geometric saturation radius of the amplitude sector, with ρ_T its macroscopic scale. Every channel response coefficient takes the single form $\kappa_X = |\beta_A| S_X(\mathcal{E}_X) \Gamma_X$, a dimensionless number bounded by order-unity projectors; the per-channel names appearing in the companion papers — κ_{MSP} , κ_{LLR} , the wide-binary plateau α_{sat} , and the population-level shear response Γ_t — are evaluations of this map on their respective channels, not independent couplings. Two magnitudes-quoted coefficients share the letter but are different objects: the κ_{Cep} and κ_{gal} of Papers 11–12 are ladder-level response slopes in magnitudes — composite products $\kappa_{\text{Cep}} = -(b/\ln 10) \lambda_{\text{Cep}}$ that convert a dimensionless depth excursion $X \sim 10^{-7}$ into a magnitude shift — not the dimensionless κ_X of this map (Paper 11, Appendix C.3). $S_\Sigma(\mathcal{E})$ and $S_A(\mathcal{E})$ are the only screening projections; environment-conditioned factors written elsewhere (S_{env} , S_{eff} , channel subscripts, or multiplicative products such as $S_{\text{local}} \times S_{\text{group}}$) denote one of these two operators evaluated on the stated environment vector. (In Section 8 the symbol L_{hom} is used for the unrelated cosmological local-to-Hubble-flow crossover scale, to keep it distinct from the GNSS L_c .)

Domain	Base coupling	Screening projection	Projector Γ_X	Observable response	Status
Solar System / GNSS	$\beta_A = -1.0$	$S_A^{(\oplus)}$ (clock depth); C_A (covariance)	$\Gamma_{\text{GNSS}} = \beta_A $	λ_T , clock response κ_{GNSS}	Derived (R12); $\lambda_T \approx R_T$ in $\mathcal{F}_X$
Wide binaries	$\beta_A = -1.0$	$\mathcal{S}_\Sigma(X_{\text{gal}})^2 y(s)$	$\Gamma_{\text{WB}} = 4\sqrt{2}/k \simeq 0.353$	α_{sat}	Derived on selected sector (predicted $\alpha_{\text{sat}} = 0.371$ at 0.44σ , Step 56/020)
Cepheids (H_0)	$\beta_A = -1.0$	$S_A(\rho_{\text{host gal}})$	$\Gamma_\mu = 5/\ln 10 \approx 2.17$	κ_{Cep}	Derived projector (R12); κ normalization open below
JWST high- z	$\beta_A = -1.0$	Stellar-population transfer	$\Gamma_{\text{gal}} = \Gamma_\mu(1+z)^{\beta_A \Delta u} \approx 2.17$	κ_{gal}	Inherited (R12)
Globular clusters	$\beta_A = -1.0$	$S_\Sigma(\text{cluster env})$	$\Gamma_{\text{MSP}} = 1$	Pulsar Γ	Derived projector (R12)
LLR / flyby	$\beta_A = -1.0$	$S_\Sigma(g_{\text{lunar}}) = 1.6 \times 10^{-14}$	$\Gamma_{\text{LLR}} = 1$	κ_{LLR}	Derived (R11, R12); screened below current LLR sensitivity

With the kinetic realization now specified (Appendix E, R11), any discrepancy between the predicted κ_X and empirical fits (such as the variation in κ_{Cep} between $0.665\text{--}1.275 \times 10^6$ mag (Paper 11 v0.12) and the reference coefficient of 0.96×10^6 mag) ceases to be an unconstrained liability and becomes a direct constraint on the transfer sector of the action.

On the canonical value and its unit. The canonical figure $\kappa_{\text{canonical}} = 0.96 \times 10^6$ mag is a prespecified response coefficient in the sense of a declared prior — held fixed so that downstream analyses (for example the JWST application, Paper 12) run without domain-specific refitting — adopted by rounding the Paper-11 joint-fit coefficient (9.72×10^5 mag) on the SH0ES sample. Its physical origin in the stellar envelope is resolved in Paper 11, Step 62 (`step_62_q_structure_derivation.json`): for a classical Cepheid at the $P_0 = 10$ d pivot period ($Q = 0.041$ d), the fundamental-mode period–mean-density relation $\langle \rho \rangle(P) = \rho_\odot(Q/P)^2$ gives $\langle \rho \rangle(10 \text{ d}) = 2.367 \times 10^{-5} \text{ g cm}^{-3}$, so the saturation-to-envelope density ratio is $\rho_T/\langle \rho \rangle(10 \text{ d}) = 8.450 \times 10^5$. Multiplied by the Wesenheit Leavitt projector $|b_W|/\ln 10 = 1.416$ mag at the unit-transport benchmark $\lambda_0 = 1$ (with bare coupling $|\beta_A| = 1$), the inverse-density carrier $\ln q = \lambda_0 X(\rho_T/\langle \rho \rangle) \propto XP^2$ predicts $|\kappa_{P^2}^{\text{pred}}(\lambda_0 = 1)| = 1.196 \times 10^6$ mag, matching the direct SH0ES full-ladder fit $|\kappa_{P^2}^{\text{fitted}}| = (1.191 \pm 0.480) \times 10^6$ mag to 0.5% (implied $\lambda_0 = 0.995 \pm 0.401$ on the physical-anchor baseline, $0.928\text{--}1.082$ across joint κ_Z variants) while outperforming the phenomenological $\log_{10} P$ carrier on χ^2 , AIC, and BIC. The unit “mag” is a bookkeeping convention inherited from the Cepheid period–luminosity relation in which the coefficient was first expressed; in the transfer-map sense of the equation above, κ_X is a dimensionless response magnitude, and the magnitude unit simply records the observational channel through which it is measured. It should not be treated as a physical dimension carried by the coupling. That separation is now a number from one profile, not an open slot. On the uniform $10^{11} M_\odot$, 30 kpc host, at 8 kpc, the same $\phi(r)$ gives $S_\Sigma = 0.99985$ and $S_A = 0.99936$. Host screening is not the Cepheid coefficient. The two clocks the ladder divides share each galactic potential, so the common rate cancels in the ratio $q = r_{\text{spec}}/r_{\text{Cep}}$. On this host against a $10^{10} M_\odot$ anchor the nested ratio is $\Delta \ln q = 2.4 \times 10^{-10}$, a clock-channel coefficient of $\kappa_{\text{nested}} = -7.5 \times 10^{-4}$ mag under the Leavitt projector $b/\ln 10$; alternative reference-clock conventions — the volume-mean light depth or the direct Cepheid-to-Cepheid comparison retaining the cross-galaxy baseline — leave $|\kappa_{\text{nested}}|$ of order unity at most and of the same sign, opposite to the measured positive response. The raw conformal clock channel is therefore negligible, more than eight orders of magnitude below the empirical interval: κ_X is carried by the envelope density-ratio response $\rho_T/\langle \rho \rangle(P)$, not by differential host clock drift. $B(\phi)$ is the family $B_0 u^2/(1+u^2) e^{-u^4/2}$ with $B_0 \geq 0$ and $B_0 \leq 78$ from the 10^{-15} cone split on this profile; the holonomy scales linearly across that interval. The kinetic sector of the R11 completion is the two-branch form $P_{,X} = k\sqrt{\xi} + 2\xi$ specified in Section 2 — with $P_{,X} \rightarrow 0$ at $\xi \rightarrow 0$, regulated at zero data cost by a small canonical term $\epsilon \lesssim 0.1$ or nonzero cosmic ambient.

Because the environmental vector $\mathcal{E}$ encompasses the total localized state (source structure, boundary conditions, and ambient fields), its operational realization depends strictly on the physical domain being probed. In dense macroscopic matter, it manifests via a density proxy; in cosmological voids and local potential wells, it tracks potential-depth gradients; in kinematic orbital phase space, it follows velocity-dispersion transitions; in geodetic clock networks, it is defined by geometric covariance lengths λ_T ; and in

subatomic environments, it is bounded by geometric proximity regulators. These are not competing mechanisms, but domain-specific macroscopic projections of the same underlying continuous saturation of the Temporal Topology.

PPN mapping

Under the canonical unified matter metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ at a fixed cosmic epoch ($A_{\text{sp}}(t_0) = 1$), slow matter responds to the temporal lapse potential $\Phi_{\text{dyn}} = \Phi_N + c^2 \beta_A u_{\text{grav}} = (1 + 2\beta_A^2 S_\Sigma)\Phi_N$ while the spatial 3-metric $\tilde{g}_{ij} = \gamma_{ij} = (1 - 2\Phi_N/c^2)\delta_{ij}$ remains unstretched ($\Psi_{\text{sp}} = \Phi_N$), so optical rays respond to $\Phi_{\text{lens}} = \frac{1}{2}(\Phi_{\text{dyn}} + \Psi_{\text{sp}}) = (1 + \beta_A^2 S_\Sigma)\Phi_N$. The PPN parameter is therefore $\gamma_{\text{PPN}} = \Psi_{\text{sp}}/\Phi_{\text{dyn}} = 1/(1 + 2\beta_A^2 S_\Sigma)$ (compared with $(1 - 2\beta_A^2 S_\Sigma)/(1 + 2\beta_A^2 S_\Sigma)$ on the isotropic-conformal benchmark), which at leading order gives the strict, sign-definite prediction $\gamma_{\text{PPN}} - 1 \simeq -2\beta_A^2 S_\Sigma < 0$, where S_Σ is the source's screening fraction (Section 2.2, Step 80). With $\alpha_0 = \sqrt{2}\beta_A = -\sqrt{2}$, Cassini's $|\gamma_{\text{PPN}} - 1| < 2.3 \times 10^{-5}$ requires the bound $S_\Sigma^{(\odot)} \lesssim 1.15 \times 10^{-5}$ (5.8×10^{-6} on the isotropic benchmark) in the Solar-System environment; evaluated directly on the selected two-branch kinetic sector $P_{,X} = k\sqrt{\xi} + 2\xi$ ($k = 16.03$) at solar conjunction ($r = 1.6 R_\odot$, $g_N = 107.1 \text{ m s}^{-2}$, $q = g_N/g_t = 3.15 \times 10^{11}$), the solved response $y_{\text{tb}} = 2.16 \times 10^{-8}$ gives $|\gamma_{\text{PPN}} - 1| \simeq 4.32 \times 10^{-8}$, more than $500\times$ below the Cassini bound. Near massive bodies, the suppression of Temporal Shear (vanishing field gradient) suppresses the effective scalar charge, cleanly preserving PPN bounds without invoking rigid thin-shell approximations.

PPN recovery in the screened limit. For $A(\phi) = \exp(\beta_A \phi/M_{\text{Pl}})$, the dimensionless microscopic coupling is $d \ln A/d\phi = \beta_A = -1$ (equivalently $\alpha_0 = \sqrt{2}\beta_A$ in DEF normalization). Environmental screening does not alter this universal microscopic coupling. Instead, it suppresses the effective exterior scalar charge,

$$\alpha_{\text{eff}} = S_\Sigma(\mathcal{E}) \alpha_0, \quad (65)$$

where $S_\Sigma(\mathcal{E}) \rightarrow 0$ in screened source/ambient configurations. In an isolated spherical kinetic benchmark, the high-acceleration condition is $g_N = GM_{\text{enc}}(r)/r^2 \gg g_t$; density alone is neither a universal cutoff nor a substitute for the solved field and boundary conditions. Because the spatial 3-metric $\tilde{g}_{ij} = \gamma_{ij}$ is unstretched while the temporal lapse carries the screened source charge, the PPN deviation is linear in the source charge fraction, enforcing the sign-definite prediction $\gamma_{\text{PPN}} - 1 < 0$:

$$\gamma_{\text{PPN}} - 1 = -\frac{\alpha_0 \alpha_{\text{eff}}}{1 + \alpha_0 \alpha_{\text{eff}}} = -\frac{2\beta_A^2 S_\Sigma}{1 + 2\beta_A^2 S_\Sigma} \quad (66)$$

$$\left(\text{isotropic benchmark: } -\frac{4\beta_A^2 S_\Sigma}{1 + 2\beta_A^2 S_\Sigma} \right),$$

which is linear in S_Σ at leading order. Therefore $S_\Sigma \rightarrow 0 \implies \alpha_{\text{eff}} \rightarrow 0 \implies \gamma_{\text{PPN}} \rightarrow 1$. The remaining PPN parameters likewise recover their GR values in the screened limit. No independent running of the frozen microscopic coupling α_0 is required.

Equivalence principle

TEP ensures universality in the matter frame. In the Einstein frame, the anomalous geometric acceleration (conventionally parameterized as a fifth force) is bounded by Eötvös experiments; MICROSCOPE gives $\eta \lesssim 10^{-15}$. Sectoral dilaton-like couplings (to α , μ , quark masses) are constrained to $|d| \lesssim 10^{-5}$ – 10^{-6} by composition tests and clock ratios.

Radiative strong-field bounds: binary pulsars and stellar interiors

The selected two-branch action's static ambient response is calculated directly in step_76 with the same nonlinear matter source and quartic potential as step_53. At the reference coupling and an Earth outer boundary of $10^8 R_\oplus$, the infinitesimal tangent is 0.6536 while the finite response to $\delta u = 2.5 \times 10^{-11}$ is 0.00199. At $10^{10} R_\oplus$ the resolved Earth interior excursion falls below reporting resolution, whereas the selected massless-vacuum control returns unit response. The measurable tangent agrees with nonlinear finite differences and mesh refinement. Smaller comparison interfaces retain near-unit response. This is a calculated potential- and domain-dependent static screening effect; selecting the physical ambient matching surface and computing finite-frequency clock transfer remain distinct from this boundary test.

The scalar-dipole calculation in step_69 separates two source prescriptions: (i) a massless kinetic-only control, $P = X + X|X|/\Lambda_X^4$, in which compact-body sensitivity charges $\alpha_i = \alpha_0(1 - 2s_i)$ are prescribed as unscreened point sources at the orbital radius $r = a$ with a reflecting Dirichlet inner wall ($T_{\text{amp}} = 0.0121$ and tightest sensitivity-bracket margin 0.529 on J1738+0333; this unscreened-source control does not pass the full bracket because it omits the screening shell between the neutron-star surface

$R_{\text{NS}} \simeq 12 \text{ km}$ and the orbital separation $a \simeq 1.73 \times 10^6 \text{ km}$, and (ii) the selected two-branch sector $P_{,X} = k\sqrt{\xi} + 2\xi$ ($k = 16.03$) with shell-impedance screening across the compact-body-to-wave-zone profile, where the binding-energy sensitivity $s_A = -\partial \ln M_A / \partial \ln G_{\text{int}}$ resides at the stellar radius $R_A \ll a$ and is suppressed across the pair shell by $T_{\text{amp}}^{\text{imp}} \simeq a/r_* = 9.2 \times 10^{-7} \text{--} 1.4 \times 10^{-5}$ (2.26×10^{-6} for J1738+0333), clearing every binary-pulsar $\dot{P}_b$ bound across the full EOS sensitivity bracket by amplitude margins of 2.8×10^3 to 3.9×10^4 at $K_D = 0.5$ (tightest margin $2,817\times$ on J1738+0333 s_{hi} ; $996\times$ to 1.39×10^4 at $K_D = 4.0$), while the hierarchical three-body operator $\mathcal{R} = y^3$ on the J0337+1715 inner binary at the outer white-dwarf separation gives $\eta_{\text{pred}} = 2.54 \times 10^{-14} \ll 2.6 \times 10^{-6}$ (margin $\sim 10^8\times$; vs. $0.089\text{--}0.165$ under the unscreened single-vertex control).

Compact-well bound at fixed ambient boundary. The selected high-gradient flux law $f(q) = kq/\sqrt{2} + q^2$ has an integrable point-source gradient, $q \sim r^{-2/3}$. For the source-only family of step_58, $0 \leq F(r) \leq 1$ because the matter coupling contributes $e^{-u} \leq 1$, hence, with $\mathcal{J}(q) = qf(q)$, $u_c \leq \int_0^{R_{\text{out}}} \mathcal{J}^{-1}(r^{-2}) dr$. The finite bound is uniform as the source radius tends to zero. At the existing dimensionless boundary $R_{\text{out}} = 40$, $u_{\text{amb}} = 0$, direct quadrature gives $u_c \leq 2.88628$ and $A_c/A_{\text{amb}} \geq 0.05578$. The existing selected-family solutions lie comfortably inside the bound ($u_c \leq 1.40872$ over the scanned radii). This is a positive local nonsingularity certificate in the stated fixed-source, fixed-boundary problem; a finite-radius logarithmic trend fit cannot imply an unbounded central well. The low-gradient logarithmic tail still makes the ambient boundary relevant, so the local bound is not a universal floor on unbounded space.

Disformal constraints

GW170817/GRB170817A constrain $|c_\gamma - c_g|/c \lesssim \text{few} \times 10^{-15}$ at $z \approx 0.01$, bounding the observable combination $B(\phi)(\partial\phi)^2$ along the observed astrophysical path. This does not require B to vanish identically. In regimes where common-mode conformal effects dominate, B may remain active as a source for synchronization holonomy, multipath propagation anomalies, or interferometric signatures without violating the same-path EM–GW timing bound.

Disformal holonomy and the screening ontology

As established in Section 3.3, the invariant synchronization observable is the GR-subtracted residual

$$H_{\text{resid}}(C) = \oint_C \Delta\sigma, \quad \Delta\sigma \equiv \tilde{\sigma} - \sigma_{\text{GR}}. \quad (67)$$

In the conformal-only subclass, the scalar clock-rate contribution is the exact one-form $d \ln A$, so it cannot by itself generate closed-loop residual synchronization holonomy in a smooth simply connected region. A leading-order nonzero H_{resid} requires residual synchronization curvature,

$$d\Delta\sigma \neq 0. \quad (68)$$

In the minimal TEP model this curvature is supplied by the disformal sector; in more general extensions it may arise from non-metricity or other explicitly non-exact transport structure.

To state the disformal contribution in a measurement-defined way, let u^μ denote the four-velocity field of the physical clock network or observer congruence used to define the synchronization protocol. The $(- + + +)$ signature is used, so that

$$u^\mu u_\mu = -1. \quad (69)$$

Let

$$P_\mu{}^\nu = \delta_\mu{}^\nu + u_\mu u^\nu \quad (70)$$

be the spatial projector into the local rest space of that congruence. To leading order in the disformal correction, the projected contribution to the synchronization connection has the representative form

$$\delta\tilde{\sigma}_\mu \simeq -\frac{B}{A^2}(u \cdot \nabla\phi)P_\mu{}^\nu\nabla_\nu\phi, \quad (71)$$

up to the sign convention used for the synchronization one-form and higher-order disformal corrections.

Appendix A3 derives this expression from the mixed time-space projection of the disformal matter metric. It also shows that synchronization re-gaugings shift both the matter-frame synchronization connection and the corresponding GR reference connection by the same exact one-form. Therefore the GR-subtracted residual connection $\Delta\sigma$ is invariant under synchronization convention changes, and

$$H_{\text{resid}}(C) = \oint_C \Delta\sigma \quad (72)$$

is independent of the arbitrary simultaneity convention used to coordinatize the specified physical clock network.

The invariant claim is therefore precise: H_{resid} is not independent of which physical clock network is used, but for a specified physical clock-network protocol it is independent of arbitrary synchronization re-labelling.

For a hypersurface-orthogonal clock network, $u^\mu = n^\mu$, the projected expression reduces to the familiar 3 + 1 form

$$\delta\tilde{\sigma}_i \approx -\frac{B}{A^2 N}(\partial_i\phi)(n \cdot \partial\phi), \quad (73)$$

where N is the lapse and n^μ is the unit normal to the spatial slices. This ADM expression should be read as a special-case representation of the physical congruence formulation, not as the definition of the observable.

Unlike $d \ln A$, the disformal contribution is not generically exact. In the local non-topological case, its curvature satisfies

$$d(\delta\tilde{\sigma}) = -\frac{B}{A^2}d\left(\frac{\dot{\phi}}{N^2}\right) \wedge d\phi \quad (74)$$

whenever the prefactor multiplying the projected scalar gradient varies independently around the loop, for example through time dependence, anisotropic boundary conditions, inhomogeneous field structure, lapse/shift structure, or spatial variation of the disformal response within a fixed physical clock-network protocol. For a loop C bounding a smooth surface Σ , the local non-exact contribution to the residual holonomy may be written

$$H_{\text{resid}}(C) = \oint_C \Delta\sigma = \iint_\Sigma d(\Delta\sigma). \quad (75)$$

At leading order beyond the GR-subtracted reference model, $d(\Delta\sigma)$ contains the disformal curvature $d(\delta\tilde{\sigma})$. Topological holonomy, where the loop does not bound a smooth surface or the connection is locally closed but not globally exact, is a separate case and is not represented by the Stokes expression above.

The conformal and disformal responses arise from the same environment-dependent scalar configuration. For the universal exponential coupling,

$$\Sigma_\mu \equiv \nabla_\mu \ln A = \frac{\beta_A}{M_{\text{Pl}}} \nabla_\mu \phi, \quad (76)$$

while the leading disformal deformation relative to the conformal metric is

$$\mathcal{D}_{\mu\nu} \equiv \frac{B(\phi)}{A^2(\phi)} \nabla_\mu \phi \nabla_\nu \phi = \frac{B(\phi) M_{\text{Pl}}^2}{A^2(\phi) \beta_A^2} \Sigma_\mu \Sigma_\nu. \quad (77)$$

Environmental flattening of the Temporal Topology therefore suppresses both responses: Temporal Shear is linear in the locally active scalar gradient, whereas the leading disformal deformation is quadratic in that gradient for fixed B/A^2 . Their observable suppression is nevertheless not represented by a single universal numerical factor, because the disformal response additionally depends on $B(\phi)$, the solved field profile, path geometry, boundary conditions, and the observer congruence. The body-level exterior source-charge factor

$$S_\Sigma \equiv Q/Q_0 \quad (78)$$

is an integrated observable projection of the field configuration and should not be inserted directly as a universal local S_Σ^2 multiplier for disformal observables. At leading disformal order, the synchronization correction may equivalently be written

$$\delta\tilde{\sigma}_\mu \simeq -\frac{B(\phi) M_{\text{Pl}}^2}{A^2(\phi) \beta_A^2} (u \cdot \Sigma) P_\mu{}^\nu \Sigma_\nu. \quad (79)$$

Thus synchronization holonomy depends on the local field value and Temporal Shear, the observer motion relative to that field, the orientation of the gradient, and the complete path geometry. Experimental response therefore cannot in general be inferred from ambient density or a body-level source-charge factor alone.

Accordingly, high-energy, mesoscopic, and topological probes should not be modeled solely by the ambient bulk-density screening function used in astrophysical applications. Their responses are represented by channel-specific coefficients κ_X , depending on momentum transfer, interaction topology, boundary geometry, and microscopic field structure. These probes test whether non-exact disformal transport remains measurable in regimes where the conformal clock-rate response is screened.

8. Cosmology: Static Spatial Geometry, Temporal Horizon, and EFT Mapping

Background & The Temporal Horizon

Supersession Note: Earlier formulations of TEP utilized phenomenological epoch-screening functions to artificially preserve a standard hot-plasma expansion history. The framework now develops thermodynamic closure natively within the canonical eternal-universe architecture. The "hot Big Bang" — a singular, hot, dense early state of an expanding space — is re-expressed in the canonical architecture as a matter-frame temporal horizon rather than a gravitational volume singularity. The observed thermal history is preserved throughout: recombination, the blackbody spectrum, and the acoustic peaks are reconstructed as conformal images of the standard history on the static background (TEP-TH, TEP-HC), and discrimination between the two readings lives where the dynamics differ — growth and lensing, clock channels, siren transport, and the native production mechanisms (TEP-BBN) — not in the CMB's gross features.

The canonical TEP cosmology is spatially infinite, non-compact, physically eternal, and inhomogeneous: space has no boundary and does not close on itself. The physical (gravitational) volume is static, while the matter-unit volume drifts. Local curvature, gravitational dynamics, shear, and motion remain permitted. The unified causal matter metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ ($d\tilde{s}^2 = -N_{\text{TEP}}^2(\mathbf{x})c^2 dt^2 + A_{\text{sp}}^2(t, \mathbf{x})\gamma_{ij}(\mathbf{x})dx^i dx^j$ at $B=0$) reduces on the homogeneous intergalactic background ($u_{\text{grav}}=0$, $N_{\text{TEP}}=1$, $\Pi_\mu^\alpha \nabla_\alpha \phi=0$) to $d\tilde{s}^2 = -c^2 dt^2 + A_{\text{sp}}^2(t)\gamma_{ij}dx^i dx^j$ (or in conformal propagation time $d\eta = dt/A_{\text{sp}}(t)$, $d\tilde{s}^2 = A_{\text{sp}}^2(\eta)[-c^2 d\eta^2 + \gamma_{ij}dx^i dx^j]$), inheriting its secular ruler evolution from the ambient drift $u_{\text{drift}}(t)$, so that the expansion inferred from redshift–distance observations is a derived consequence of temporal-field ruler transport rather than growth of physical volume in either sector (Paper 30, Appendix C). Because the spatially covariant ADM gravitational action S_{grav} on static space $\gamma_{ij}(\mathbf{x})$ carries constant M_{Pl}^2 and constant WKB tensor weight $\sqrt{A_{\text{sp}}^{+1} \cdot A_{\text{sp}}^{-1}} \equiv 1$ in conformal time η (Section 2.2, Step 80), no coordinate transformation or field redefinition maps the gravitational and matter sectors simultaneously onto a minimally coupled expanding FLRW spacetime; the two sectors carry independent physical content, and their separation is itself observable through the diffeomorphism-invariant standard-siren ratio $\Xi(z) = d_L^{\text{GW}}/d_L^{\text{EM}} = 1/(1+z) \neq 1$ (standard sirens, below). The temporal horizon bounds the history accessible to an observer; it is not an edge of space or a beginning of the universe, and the finite age reconstructed from cosmological observation is distinguished from the universe's infinite physical history.

Cosmological expansion in TEP is a chronometric projection rather than a spatial collapse. The resolution arises natively from the dual-metric foundation:

1. **Gravitational Frame:** The underlying gravitational manifold $g_{\mu\nu}$ is static. The number density is constant in the gravitational frame; the matter energy density there scales as A , which the scalar sector must balance to maintain a static $g_{\mu\nu}$. The gravitational volume V_g of any coordinate region does not change.
2. **Matter Frame:** Because local Lorentz invariance is strictly maintained (Axiom 2), the local speed of light $c = 1$ is invariant in any freely falling frame of the matter metric $\tilde{g}_{\mu\nu}$. Consequently, if the matter unit of time scales by the conformal factor $A(\phi)$, the matter unit of length must scale identically. The physical volume of a coordinate region, measured in matter units, is therefore $\tilde{V} \propto A^3 V_g$.

Conservation of matter mass M then dictates that the matter density, measured by local observers, evolves as $\tilde{\rho} = M/\tilde{V} \propto A^{-3}$. Given the observational clock map $A_{\text{clock}}(z) = (1+z)^{-1}$ — adopted here as a consistency input, its derivation from the realized landscape being part of the open cosmological construction — this yields the standard cosmological density history:

$$\tilde{\rho}(z) = \tilde{\rho}_0(1+z)^3 \quad (80)$$

The matter-unit density history of standard cosmology, $\tilde{\rho}(z) = \tilde{\rho}_0(1+z)^3$, then reads as unit drift — the conformal recalibration of matter-frame distance units at temporal depth ($A \rightarrow 0$) — rather than by a physical crushing of gravitational space. The density scaling alone does not settle the corresponding dimensionless ratios (for example T/m_e at the emitting region); those follow from the Proper-Time Reaction Flow below, and are the observables that distinguish the two readings. Distances and densities expressed in matter units evolve without any physical stretching. This dual-frame resolution removes the need for mechanical balance mechanisms: neither a negative disformal coupling ($B < 0$) nor complex matter-flow partitions are required to cancel volume expansion artificially, because there is no volume expansion in the gravitational frame to begin with.

Solving the rolling-floor ansatz $u(r, t) = U(r) - \bar{\Pi} t$ directly on a Painlevé–Gullstrand interior background — regular across r_h , with the shift $\beta^r = \sqrt{2M/r}$ encoding the relativistic infall — refines this picture in three ways (Appendix E, R3). First, the scalar profile steepens toward the horizon, reaching $u \simeq 9\text{--}10$ at $1.01 r_h$, smoothly connecting the weak-field exterior to the finite-minimum temporal floor. Second, the solution lands natively on the temporal-well branch the cosmology requires ($A < 1$), identifying the deep-well boundary with the operational clock-rate horizon of TEP-TH and distinguishing it from the disformal degeneracy surface $\det \tilde{g}_{2D} = 0$ and from the prescribed $A \rightarrow \infty$ test profile that TEP-BH shows to be unattainable on a fixed Schwarzschild background (its Theorem D.1); the dynamics select the cosmological branch rather than being assigned it — the same temporal-well branch on which the TEP-BH coupled construction lands at $\eta = +0.3$. Third, self-consistency of the rolling ansatz requires $\square u$ to be time-independent along the roll, which holds only when the interior drive is locally flat: a constant $V_{,u} + \mathcal{Q}_m$ closes to 7×10^{-14} , while steep or exponential potentials fail secularly — the floor region demands a locally flat potential or a matter-dominated source, a derived constraint on the $V(\phi)$ programme rather than an assumed one.

The candidate master potential is

$$V(u) = V_{\text{matter}}(u)e^{-(u/u_s)^4} + V_0 e^{-(u_s/u)^4} \quad (81)$$

The transition scale (u_s) must be selected so that the deep-field sector contributes to the temporal-well solution as the scalar reaches $u \sim 9\text{--}10$, while the total potential remains compatible with the field values and gravitational constraints of the cosmological matter-hosting landscape. These are simultaneous requirements on a single potential, not independently adjustable mechanisms. The floor V_0 and the precise transition scale are fixed by that joint compatibility calculation, which remains open; pending its completion, $V(u)$ is a parametrized family rather than a fixed potential.

Temporal-well construction target. Paper 28 develops exterior and interior benchmarks; their completion into one globally regular static mass family is not assumed here. The target interprets a black hole not as a collapsed singular object but as a temporal well: gravitationally regular space in which the matter clock rate drops to a finite, non-zero minimum ($N_{\min} > 0$), never actually reaching or asymptotically approaching zero. The scope of this statement is the deep-well sector: it is the local coupling inside a temporal well that is floored by the master potential V_0 . The cosmological temporal horizon discussed below is a different object — on the homogeneous closed branch the conformal factor itself approaches $A \rightarrow 0$ as $\rho_m \rightarrow 0$, and on the inhomogeneous realization it is the reconstructed observational clock map $A_{\text{clock,obs}} \equiv 1/(1+z)$ that vanishes as $z \rightarrow \infty$. Neither statement assigns a zero clock rate to a local well interior. What standard general-relativistic interpretation reads as collapse is the extreme slowing of matter-frame time transport. The underlying gravitational metric g never collapses and its radial coordinate never becomes timelike; the interior is gravitationally regular, static space, not an expanding geometry, and the field equations remain strictly static all the way to $r = 0$. The Temporal Horizon is not an absolute causal barrier, but an operational, observer-relative boundary of practical signal inaccessibility where extreme gravitational redshift renders signals practically undetectable from the exterior. Because the core

density is generated by the master potential floor V_0 , the interior is completely scale-invariant: supermassive black holes like M87* and Sgr A* share the exact same static regular core as stellar-mass wells, differing only in their spatial extent. Externally, a temporal well reproduces the shadow, photon sphere, and orbital dynamics of a standard black hole. The temporal roll on cosmic scales and the horizon structure in deep wells are dual manifestations of the universal scalar sector: the ambient field evolves over cosmic time across the landscape, while establishing regular, static potential wells around compact mass concentrations.

The scalar field on this background is not a homogeneous fluid but a dynamic, inhomogeneous network. At any given coordinate time t , the field forms a lumpy temporal landscape where local wells and voids possess distinct local values—an undulating terrain of temporal "hills" (voids where clocks run faster) and "valleys" (gravitational wells where clocks run slower). Light reaches the observer by propagating through this evolving landscape over cosmic journeys spanning billions of years, and the measured redshift is the record of that passage. The Temporal Shear $\Sigma_\mu = \nabla_\mu \ln A(\phi)$ (Appendix A.3) is a spatial gradient, so its accumulated effect along a null ray is exact whenever the background is stationary: along each ray, k_t is conserved by the timelike Killing symmetry of a static g — the conformal factor drops out of the null covector, so $\dot{k}_t = 0$ holds even when A varies spatially along the path — so the endpoint form generalizes to $1 + z = (AN)_{\text{obs}}/(AN)_{\text{em}}$ with N the gravitational lapse (so that AN is the matter-frame lapse), without any assumption of spatial homogeneity of A : the conformal part of the redshift depends on the macroscopic historical trend of the field values hosting matter over coordinate time. This telescoping is a statement about the net frequency bookkeeping, not about the photon's interaction with the terrain: the ray responds to the matter-frame topology continuously, at every point of the path — each well blueshifts the locally measured frequency on descent and redshifts it on ascent, asymmetric entry and exit slice the residual to the intervening field difference, and the dwell time accumulated while crossing each nested structure is positive and never returned. Nested and overlapping structures are handled by the total solved field rather than by independent additive kicks; on a strictly static background only the frequency sum collapses to the endpoints. Crucially, the physical landscape is dynamic: as the photon journeys across space, background time continues to evolve, and the intervening hills and valleys are themselves moving and evolving over time. Where the fields evolve during transit ($\partial_t \ln A \neq 0$, $\partial_t N \neq 0$), a path-integrated (integrated Sachs–Wolfe and Rees–Sciama type) contribution arises — each nested structure contributing in proportion to its own evolution rate and the time the photon dwells within it — and the disformal sector contributes its own non-exact transport; both are intrinsic parts of the total redshift rather than external corrections, computed within the same moving-endpoint framework alongside endpoint kinematics.

Along a Solar-System observer's worldline embedded in the continuous nested hierarchy (with continuous Temporal-Topology gradient flattening on the selected two-branch kinetic operator $P_X(\xi) = k\sqrt{\xi} + 2\xi$ and smooth quartic potential $V(u) = \frac{\lambda}{4}M_{\text{Pl}}^4 u^4$, involving no thin-shell boundary; Steps 53, 70, 76), the continuous radial profile connects the screened interior ruler drift $u_{\text{int}}(t)$ to the rolling intergalactic ambient $\bar{u}_{\text{amb}}(t)$. In the $(3+1)$ ADM decomposition on static gravitational space $\gamma_{ij}(\mathbf{x})$ with strictly constant M_{Pl} in S_{grav} , $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(\phi(t, \mathbf{x}))\Pi_{\mu\nu}$ ($d\tilde{s}^2 = -N_{\text{TEP}}^2(\mathbf{x})c^2 dt^2 + A_{\text{sp}}^2(t, \mathbf{x})\gamma_{ij}(\mathbf{x})dx^i dx^j$), where $N_{\text{TEP}}(\mathbf{x}) = \exp(-u_{\text{grav}}(\mathbf{x}))N_{\text{GR}}(\mathbf{x})$ is the stationary baryon-sourced gravitational/scalar lapse ($\partial_t u_{\text{grav}} = 0$, $|u_{\text{grav}}| \sim 10^{-6}$, so virialized galaxies never accumulate a secularly growing $\mathcal{O}(1)$ potential cliff relative to the IGM) and $A_{\text{sp}}(t, \mathbf{x}) = \exp(\beta_A u_{\text{drift}}(t, \mathbf{x})) = \exp(-u_{\text{drift}}(t, \mathbf{x}))$ is the matter-frame spatial ruler factor ($\partial_t \ln A_{\text{sp}} = -\partial_t u_{\text{drift}} = +H_{\text{drift}} > 0$) measuring how many matter-frame atomic Bohr radii ($\ell_{\text{unit}}^{\text{coord}} = \ell_0/A_{\text{sp}} = \exp(+u_{\text{drift}})\ell_0$ in static gravitational coordinates) fit across a fixed static coordinate interval dx ($d\tilde{\ell} = A_{\text{sp}} dx$). For any static-coordinate matter observer with unit 4-velocity $\tilde{u}^\mu = (N_{\text{TEP}}^{-1}, \mathbf{0})$ and measured proper frequency $\tilde{\omega} = -\tilde{u}^\mu k_\mu = E(t)/N_{\text{TEP}}(\mathbf{x})$ ($E \equiv -k_t$), Hamilton's null equations $dx/dt = N_{\text{TEP}}/A_{\text{sp}}$ and $d \ln E/dt = \partial_t \ln N_{\text{TEP}} - \partial_t \ln A_{\text{sp}}$ cancel $\partial_t \ln N_{\text{TEP}}$ identically against $d \ln N_{\text{TEP}}/dt$ at every point along the photon trajectory, leaving the universal differential-geometric redshift identity over lookback interval $\Delta t = t_{\text{now}} - t_{\text{em}}$ ($\Delta \bar{u}_{\text{amb}} = u_{\text{drift}}(t_e) - u_{\text{drift}}(t_o) = \ln(1 + z_{\text{cosmo}})$; Step 70):

$$\begin{aligned} \ln(1+z) &= \ln\left(\frac{\tilde{\omega}_e}{\tilde{\omega}_o}\right) = \int_{t_e}^{t_o} \frac{\partial \ln A_{\text{sp}}(t, x(t))}{\partial t} dt + \int_{x_e}^{x_o} \frac{\partial \ln N_{\text{TEP}}(x)}{\partial x} dx \\ &= \underbrace{T_{\text{cosmo}} \Delta \bar{u}_{\text{amb}}}_{\text{(a) screened endpoint interior drift}} + \underbrace{(1 - T_{\text{cosmo}}) f_{\text{IGM}} \Delta \bar{u}_{\text{amb}}}_{\text{(b) in-flight IGM ruler-drift integral } \int (-\partial_t u_{\text{drift}}) dt} + \underbrace{\delta u_{\text{env}}}_{\text{(c) stationary well}} \\ &= [1 - f_{\text{well}}(1 - T_{\text{cosmo}})] \Delta \bar{u}_{\text{amb}} + \delta u_{\text{env}}, \end{aligned}$$

where $T_{\text{cosmo}} \equiv \Delta u_{\text{int}}/\Delta \bar{u}_{\text{amb}} \in [0, 1]$ is the continuous boundary susceptibility of the host interiors, $f_{\text{well}} \equiv \frac{1}{L} \int_0^L W_{\text{well}}(x) dx \in [0, 1]$ is the sightline fraction occupied by screened wells, and $f_{\text{IGM}} = 1 - f_{\text{well}} \in [0, 1]$ is the sightline fraction spent in the unscreened intergalactic medium. Because $\partial_t \ln N$ cancels identically along any ray between $d \ln E/dt$ and $d \ln N/dt$, placing the cosmic roll in $N(t)$ alone with $A_{\text{sp}} = 1$ would reduce to a trivial time-coordinate relabeling of Minkowski space ($\ln(1+z) = 0$), while placing a counter-rolling step inside $N(t, \mathbf{x})$ would build an unphysical $\mathcal{O}(1)$ potential cliff $\Delta \ln N \sim -(1-T)H_0 t$ between galaxies and the IGM; in the canonical unified metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ ($d\tilde{s}^2 = -N_{\text{TEP}}^2(\mathbf{x})c^2 dt^2 + A_{\text{sp}}^2(t, \mathbf{x})\gamma_{ij}(\mathbf{x})dx^i dx^j$), the stationary lapse $N_{\text{TEP}}(\mathbf{x})$ has zero secular cliff while the ruler-drift factor $A_{\text{sp}}(t, \mathbf{x})$ across the unscreened IGM ($f_{\text{IGM}} = 1 - f_{\text{well}} \rightarrow 1$) redshifts the photon continuously in flight. Simultaneously, because Step 80's spatially covariant ADM gravitational action $S_{\text{grav}} = \frac{1}{2}M_{\text{Pl}}^2 \int d^3x dt \sqrt{\gamma} N_{\text{GR}}[R_{\text{scalar}}^{(3)}(\gamma) + A_{\text{sp}}^{-1}R_{\text{TT}}^{(3)}(\gamma) + (A_{\text{sp}}/A_{\text{loc}}^2)(K_{ij}K^{ij} - K^2)]$ equips transverse-traceless

gravitational waves h_{ij}^{TT} with the exact same principal wave operator $\square_{\text{TEP}} = -(N_{\text{TEP}}c)^{-2}\partial_t^2 + A_{\text{sp}}^{-2}\gamma^{kl}\partial_k\partial_l$ as Maxwell's equations while keeping the WKB tensor measure $\sqrt{A_{\text{sp}}^{+1} \cdot A_{\text{sp}}^{-1}} \equiv 1$ constant on static space ($\sqrt{\gamma} = 1$), photons and gravitons propagate at the identical coordinate speed $c_{\text{GW}}(t, \mathbf{x}) = c_\gamma(t, \mathbf{x}) = c N_{\text{TEP}}(\mathbf{x})/A_{\text{sp}}(t, \mathbf{x})$ at every event ($\Delta t_{\gamma-\text{GW}} \equiv 0.0$ s for GW170817, compared with a 6.9×10^5 yr offset if A_{sp} were omitted from S_{grav}) while experiencing zero FLRW Hubble friction, preserving $\Xi(z) = d_L^{\text{GW}}/d_L^{\text{EM}} = 1/(1+z) \neq 1$. With strictly constant M_{Pl} in S_{grav} and $G_{\text{loc}}(\phi) = G_* A^2(\phi)(1 + \alpha_{\text{amb}}^2)$ (matching Paper 27 and Step 80), the Step 76 continuous two-branch + quartic profile suppresses the Solar-System interior response at $10^8 R_\oplus \approx 4.3 \times 10^3$ AU (≈ 0.02 pc) to a resolved static tangent $T_{\text{tan}}^{\text{Cassini}} = 1.18 \times 10^{-8}$ on the operative Cassini-compatible $10^5 \lambda_{\text{ref}}$ branch — yielding $|\dot{A}/A|_{\text{loc}} = 8.42 \times 10^{-19} \text{ yr}^{-1}$ and $|\dot{G}_{\text{loc}}/G_{\text{loc}}|_{\text{LLR}} = 1.68 \times 10^{-18} \text{ yr}^{-1}$, more than 4×10^4 times below both the Hofmann & Müller (2018) bound $(7.1 \pm 7.6) \times 10^{-14} \text{ yr}^{-1}$ and the Williams et al. bound $4 \times 10^{-13} \text{ yr}^{-1}$ — while even the conservative reference-branch (λ_{ref}) finite-excursion secant $T_{\text{cont}} = 1.99 \times 10^{-3}$ at $10^8 R_\oplus$ (static tangent 0.654; $\leq 10^{-5}$ at $10^{10} R_\oplus \approx 2.1$ pc) yields $|\dot{A}/A|_{\text{loc}} = 1.43 \times 10^{-13} \text{ yr}^{-1}$ and $|\dot{G}_{\text{loc}}/G_{\text{loc}}|_{\text{LLR}} = 2.85 \times 10^{-13} \text{ yr}^{-1} < 4 \times 10^{-13} \text{ yr}^{-1}$ (this unscreened comparison ceiling satisfies the Williams et al. bound only; the operative screened branch satisfies both LLR analyses) (plus the two-branch scalar-force self-energy drift $2H_0 y_{\text{tb}}(1 \text{ AU}) = 2.10 \times 10^{-15} \text{ yr}^{-1} \ll 7.1 \times 10^{-14} \text{ yr}^{-1}$, with `solve_ivp` Keplerian ODE integration confirming $\tilde{r}/\tilde{r}_0 = 0.99688$ versus the unscreened $T = 1$ shrinkage $\tilde{r}/\tilde{r}_0 = A^{-2} = 0.20186$), while explicit `solve_ivp` ray-tracing with full endpoint 4-velocity normalization $\tilde{\omega} = -\tilde{u}^\mu k_\mu$ recovers $\ln(1+z) = 0.09531 = \ln 1.1$ (100.00% of the Hubble law for IGM-to-IGM and at the physical $10^8 R_\oplus$ screening scale where $f_{\text{IGM}} = 1.000000, 0.09504$ [99.72%] for two halo-scale wells with $f_{\text{IGM}} = 0.9972, 0.08972$ [94.13%] for 20 intervening halo-scale wells with $f_{\text{IGM}} = 0.9421$ at $z = 0.1$, and linear Hubble scaling across the Lyman- α forest lookback sweep $\Delta \in [0.02, 0.20]$; Step 70; deriving the time-dependent cosmological matching transfer beyond static Dirichlet boundaries remains part of the open full-evolution problem).

The three times involved must be kept distinct: the gravitational coordinate time t in which the stationary metric g is written; the dynamical (ephemeris) time into which orbital fits absorb; and the matter proper time $\tilde{r}$ of atomic clocks and ranging codes, which locally runs on $A(\phi) dt$. A universal drift of A rescales every matter clock and ruler together and therefore cancels from comparisons among them — clock-only networks are blind to it by construction. Lunar laser ranging is not a clock-only comparison: it measures dynamics governed by g against a readout governed by $\tilde{g}$, which is precisely the mixed channel in which a secular drift of A would appear, as $\dot{G}/G$. The same mixed comparison motivates the clock-sector interpretation tested in Paper 17; the detected quantity there is the post-fit synodic range coefficient, whose absolute field-to-range mapping is not supplied by the clock identity alone.

The general observable is $1+z = (-\tilde{k}_\mu \tilde{u}^\mu)_{\text{em}}/(-\tilde{k}_\mu \tilde{u}^\mu)_{\text{obs}}$ with $\tilde{u}^\mu$ the physical four-velocities of the emitting and receiving galaxies, so that genuine relative motion contributes to the measured redshift on the same footing as the temporal-geometry contribution. Applying it requires a moving-endpoint problem: emitter and receiver worldlines are evolved through the matter metric and the photon must satisfy the meeting condition $\mathbf{x}_\gamma(t_{\text{arr}}) = \mathbf{x}_{\text{obs}}(t_{\text{arr}})$ on the observer's past light cone; the energy ratio then already incorporates the appropriate motion and must not be supplemented by a separate Doppler correction. The redshift alone is not the observational prediction: the angular-diameter distance must be obtained simultaneously from the Sachs optical equation for the photon bundle in $\tilde{g}_{\mu\nu}$, with $D_L = (1+z)^2 D_A$ under photon-number conservation, so the completed calculation delivers $z(\mathbf{x})$ and D_A together.

The two contributions to the measured redshift separate cleanly by scale. For a photon traversing a distance L between congruence members, the matter-frame frequency ratio combines the drift of the matter-hosting field values accumulated over lookback time with endpoint kinematics,

$$1+z \simeq \exp(H_{\text{drift}} L/c) \frac{1 + \mathbf{v}_{\text{em}} \cdot \hat{n}}{1 + \mathbf{v}_{\text{obs}} \cdot \hat{n}}, \quad (83)$$

with $\hat{n}$ the source direction on the sky, $\mathbf{v} \cdot \hat{n}$ the recession velocity, and $H_{\text{drift}} \equiv -\dot{u}$ (in $M_{\text{Pl}} = 1$ units) the macroscopic drift rate of the field values hosting the emitting and observing matter. The temporal drift establishes the overall Hubble flow, while the Doppler factor is bounded by local peculiar velocities. The local redshift field is therefore scatter-dominated — including blueshifted nearby galaxies — and the smooth linear relation emerges only beyond the crossover scale $L_{\text{hom}} \sim c|\mathbf{v}_{\text{pec}}|/H_{\text{drift}}$: for $v_{\text{pec}} \sim 10^{-3}c$ and $H_{\text{drift}} \sim H_0 \approx 2.3 \times 10^{-4} \text{ Mpc}^{-1}$, $L_{\text{hom}} \approx 4 \text{ Mpc}$. (This homogeneity crossover is distinct from the GNSS covariance length L_c of Section 7.) The transition from local kinematic noise to the Hubble flow is thereby a structural expectation of the nested temporal landscape rather than an environmental accident. Because the global drift operates on an inhomogeneous spatial landscape, observations carry a small predicted dispersion in the redshift–distance relation of order the endpoint $\ln A$ contrast between the emission and observation host wells: a falsifiable signature of landscape inhomogeneity that a perfectly smooth FLRW metric expansion does not naturally produce without extensive dark matter tuning.

The non-expansion requirement is a consistency condition on the scalar sector rather than a free assumption, and the gravitational constraint equations determine which spatial geometries can realize it. On a maximal slice ($\mathcal{K} = 0$; the traceless part of $\mathcal{K}_{ij}$ remains free, so local deformation is permitted) the Hamiltonian constraint reads ${}^{(3)}R = 2\rho_{\text{tot}}/M_{\text{Pl}}^2 + \mathcal{K}_{ij}\mathcal{K}^{ij} \geq 0$ for nonnegative total energy. Exactly flat static sections would require $\rho_{\text{tot}} \leq -\frac{1}{2}M_{\text{Pl}}^2\mathcal{K}_{ij}\mathcal{K}^{ij} \leq 0$, which is impossible for strictly positive total energy.

The realized background is accordingly volume-static rather than strictly time-independent: the spatial metric determinant is preserved along the congruence while the lapse and Newtonian-sector potentials respond to the evolving landscape. This is a statement about the total energy density entering the constraint, not an equivalence between negative energy and ghost structure — a negative scalar potential can lower ρ_{tot} without reversing the kinetic sign, and the further restrictions imposed by the full Einstein equations must be analyzed separately. Standard homogeneous kinetic-braiding contributions, being proportional to the expansion rate, vanish identically in the static limit. The static requirement therefore does not select flatness. For a homogeneous isotropic realization the constraint sharpens to the classical Einstein-static result — positive curvature everywhere, hence a closed three-sphere of finite volume — whereas on a noncompact inhomogeneous manifold no such conclusion follows, positive scalar curvature being compatible with infinite spatial extent. The homogeneous closed branch is therefore retained strictly as an analytical benchmark: evidence that the specified action admits a static, eternal configuration at all, not a model of the physical universe's topology. On that benchmark, with dust-like matter transported by the conformal exchange, $\rho_m = \bar{\rho} A(\phi)$, the Einstein equations for a static 3-sphere of radius a ,

$$3M_{\text{Pl}}^2/a^2 = \rho_m + \frac{1}{2}\dot{\phi}^2 + V(\phi), \quad -M_{\text{Pl}}^2/a^2 = \frac{1}{2}\dot{\phi}^2 - V(\phi), \quad (84)$$

together with the scalar equation of motion, are satisfied identically by the exact potential

$$V(\phi) = \frac{2M_{\text{Pl}}^2}{a^2} - \frac{\bar{\rho}}{2} A(\phi), \quad \dot{\phi}^2 = \frac{2M_{\text{Pl}}^2}{a^2} - \rho_m, \quad (85)$$

giving a closed, static, eternal gravitational solution with $V > 0$ and no ghost degrees of freedom (verified numerically, residuals $< 10^{-11}$, Appendix E, R4). On this branch the temporal horizon is approached as $\rho_m \rightarrow 0$ ($A \rightarrow 0$), the accumulated matter-frame proper time remains finite, and the apparent expansion reverses at the turnaround density $\rho_m = 2M_{\text{Pl}}^2/a^2$. Because the homogeneous solution carries no spatial gradient, its disformal volume-compensation term vanishes ($Q = 0$) and its matter-frame volume does evolve ($\tilde{a} = aA$): it exhibits gravitational staticity together with temporal redshift — the gravitational volume is static and the matter-unit evolution $\tilde{a} = aA$ is the conformal unit drift of the general case. Two transport rates must be distinguished. The conformal-drift rate per gravitational coordinate time, $\dot{A}/A$, follows $H_t(z)/H_t(0) = \sqrt{1 + 3\Omega_0 z/(1+z)}$ and saturates at high redshift; the operational rate measured by matter clocks, $H_{\text{matter}} = (aA)^{-1}d(aA)/d\tau = \dot{A}/A^2$ with $d\tau = A dt$, carries an additional factor of $1 + z$,

$$H_{\text{matter}}(z)/H_{\text{matter},0} = (1+z)\sqrt{1 + 3\Omega_0 z/(1+z)}, \quad (86)$$

growing linearly at high redshift rather than as $(1+z)^{3/2}$ — a property of the closed-static branch, not yet a prediction of the inhomogeneous realization. The reconstructed potential is to be read as a constraint on the master family rather than a demonstration of it: it fixes what the matter-domain factor $V_{\text{matter}}(u)$ must approach on the closed branch and identifies the deep-field floor with the curvature scale, $V_0 = 2M_{\text{Pl}}^2/a^2$ — the same constant toward which the reconstructed profile asymptotes as $u \rightarrow \infty$ ($A \rightarrow 0$). An exact algebraic representation within the parametrized family is exhibited explicitly (Appendix E, R4): the family member with $V_{\text{matter}}(u) = [V_{\text{rec}}(u) - V_0 e^{-(u/u_s)^4}]e^{+(u/u_s)^4}$ reproduces the reconstructed profile identically (fractional deviation $\sim 10^{-16}$ over the branch), while the natural shallow member $V_{\text{matter}}(u) = V_{\text{rec}}(u)$, $V_0 = 2M_{\text{Pl}}^2/a^2$ departs from it only inside the transition band ($\lesssim 6\%$ below $u_s/2$, a $\sim 26\%$ dip localized at $u \sim u_s$, asymptotically exact at the floor). The screening–interior join can therefore be modeled analytically: the candidate master potential introduced above smoothly accommodates the weak-field background without disrupting the kinetic screening and flattens onto the floor V_0 at deep-well field values. The remaining open condition is quantitative: any candidate potential must remain compatible with the cosmological field range $\Delta u \sim \ln(1+z)$ required by conformal unit drift while flattening onto the deep-well floor — the weak-field screening burden being carried by the kinetic sector of Section 2.2 rather than by $V(\phi)$ — a compatibility whose demonstration belongs to the inhomogeneous solution. The corresponding derivation-level open item is the extension of the Section-4 stability proofs to the noncanonical kinetic branch, not the potential range.

Localized positive-energy structure is accommodated on non-expanding slices through the Lichnerowicz form of the Hamiltonian constraint: writing $h_{ij} = \psi^4 \hat{h}_{ij}$ with $\mathcal{K} = 0$, trace-free extrinsic curvature $\mathcal{K}^{ij} = \psi^{-10} \hat{\mathcal{A}}^{ij}$, and scalar momentum $\Pi = n^\mu \nabla_\mu \phi$,

$$\hat{\nabla}^2 \psi = \frac{\hat{R}}{8} \psi - \frac{1}{8} \psi^{-7} \hat{\mathcal{A}}_{ij} \hat{\mathcal{A}}^{ij} - \frac{\psi^5}{4M_{\text{Pl}}^2} (\rho_m + V + \frac{1}{2} \Pi^2) - \frac{\psi}{8M_{\text{Pl}}^2} |\hat{\nabla} \phi|^2, \quad (87)$$

supplemented by the momentum constraint — an inhomogeneous field with $\dot{\phi} \neq 0$ and $\nabla_i \phi \neq 0$ generally carries momentum, requiring compensating matter momentum or an appropriately constructed configuration. Preservation of $\mathcal{K} = 0$ under evolution imposes the maximal-slicing lapse equation $D^2 N = N(\mathcal{K}_{ij} \mathcal{K}^{ij} + (\rho_{\text{total}} + S_{\text{total}})/2M_{\text{Pl}}^2)$, with the source taken from the exact (untruncated) matter stress tensor of Section 2; an initial zero-expansion state is insufficient if the coupled evolution immediately drives it away, and Raychaudhuri's equation — $\nabla_\mu a^\mu = \sigma_{\mu\nu} \sigma^{\mu\nu} + R_{\mu\nu} u^\mu u^\nu$ for a nonrotating zero-expansion congruence — identifies precisely which acceleration, curvature or shear terms must balance to keep the congruence non-expanding. The $\hat{R}\psi/8$ term is essential on closed slices, where the equation would otherwise admit no positive solution; on the intended noncompact slices $\hat{R}$ is unconstrained in sign. The shear term $\hat{\mathcal{A}}_{ij} \hat{\mathcal{A}}^{ij}$ is the precise place where the permitted volume-preserving deformation enters the constraint. This defines a constraint problem for initial data — the spatial realization of the inhomogeneous temporal network through which the macroscopic shear trend is expressed — and is to be distinguished from an evolved solution: the homogeneous closed branch does not by itself establish existence of the required inhomogeneous cosmos. That existence has now been demonstrated numerically (Appendix E, R8): on a periodic cell whose universal cover is a non-compact inhomogeneous slice, the constraint admits a smooth positive conformal factor for a landscape of matter-hosting wells embedded in a void sector, converging to residual $\sim 10^{-10}$ under a bordered Newton solve of the full nonlinear equation. The Gauss integrability condition $\int \psi^5 \rho_{\text{tot}} dV = -\frac{1}{2} \int \psi |\hat{\nabla} \phi|^2 dV - \frac{1}{2} M_{\text{Pl}}^2 \int \psi^{-7} \hat{\mathcal{A}}^2 dV < 0$ makes one structural feature compulsory rather than optional: on the non-compact covering slice the eternal solution requires the total energy density to change sign across the landscape — positive inside matter-hosting wells, negative in the void sector. Only the scalar potential can carry the negative budget, and the master family supplies it natively: the reconstructed branch $V_{\text{rec}}(u) = V_0 - \frac{\rho}{2} e^{-u}$ crosses zero at $u_* = \ln(\bar{\rho} a^2 / 4M_{\text{Pl}}^2) = -\ln 2 \simeq -0.6931 < 0$, so void field values $u_{\text{void}} < u_*$ — where matter clocks run faster than ambient — carry $V < 0$ natively (verified in Step 20 both on the shifted positive- u benchmark $u_{\text{void}} = +0.8$, where the bordered Newton offset $\lambda_* = -2.42$ supplies the negative energy, and on the native negative- V_{rec} void realization $u_{\text{void}} = -0.85 < u_*$, where 8,496 void cells carry $V(u) < 0$ natively before any shift with $V_{\text{min}} = -0.3396$ and converged $\psi \in [0.9985, 1.0029]$). The mean gravitational-frame curvature on the solved slice is driven to $\sim 10^{-3}$ of the local scale rather than to the closed branch's uniform positive value. The lapse and momentum/shear calculations sharpen the scope of this construction (Appendix E, R13). The canonical lapse calculation uses $\rho_\phi + S_\phi = 2\Pi^2 - 2V_{\text{eff}}$ and the covariant Laplacian $D_h^2 N = \psi^{-6} \nabla \cdot (\psi^2 \nabla N)$. On the prescribed periodic landscape, the unmodified lapse source is positive. A spectral shift can produce a positive zero-mode lapse, but at fixed Hamiltonian budget that shift requires $\Pi^2 < 0$ and is inadmissible for a real canonical scalar. Step 21 instead retains the original physical source with $\Pi = 0$ and solves $(-D_h^2 + q)N = C$, normalized by $\langle N \rangle_{\sqrt{h}} = 1$. It obtains a positive lapse on both 16^3 and 48^3 grids, with relative residual below 10^{-10} ; $C = \partial_t \mathcal{K}$ is spatially uniform and nonzero. This establishes an evolving constant-mean-curvature initial-slice benchmark without negative kinetic energy. It does not establish preservation of $\mathcal{K} = 0$, long-time evolution or the complete noncanonical cosmological branch. Exact non-expansion remains a condition to demonstrate for the intended eternal realization. Second, the momentum/shear sector is now solved rather than assumed away: the drift momentum of the scalar on the gradient landscape sources the momentum constraint through $j_i \propto \Pi \hat{\nabla}_i u$, the conformal Killing construction $\hat{\mathcal{A}}_{ij} = (\hat{L}W)_{ij}$ satisfies the constraint identically, and the full Hamiltonian equation including the $\hat{\mathcal{A}}^2 \psi^{-7}/8$ volume-preserving-shear term admits a positive conformal factor at every drift amplitude scanned ($c_\Pi = 0-8$; $\psi \in [0.75, 1.81]$ throughout), with the linearized constraint operator invertible at each solution — no flat or marginal direction, so the data are locally unique. The momentum/shear scans establish their specified initial-data constructions; they are not the same solution as the zero-momentum lapse benchmark, and global non-expanding evolution remains open. An initial evolution attempt on prescribed wells failed at the initial-data level, and diagnosing it identified a construction error rather than a defect of the drift law. On the prescribed slice the scalar equation of motion carried an rms residual of order 10^2 at $t = 0$, so the integration relaxed off its constraint shell rather than evolved; the apparent drift reversal within $\Delta t \sim 0.01$ is reproduced exactly by a momentum kick opposing the ambient slope, which turns any positive Π at $t \sim \Pi_0/|\lambda_c| \sim 0.02$, where λ_c is the periodic-domain solvability constant of the scalar equation (of order the constraint offset λ_*). The uniform part of the scalar residual is the homogeneous roll itself, not an error term: on the reconstructed branch $V_{,u} \propto e^{-u} > 0$ drives u downward, so matter clocks ran slower at earlier times — the secular redshift trend is the natural downhill roll, not an imposed motion. With the field instead solved from its elliptic equation on the matter landscape — a bordered Newton solve of $D^2 u = V_{,u} - \rho_m + \lambda_c$ in mean-field gauge, iterated against the Lichnerowicz solve — the initial slice satisfies the scalar equation to 10^{-8} and the constraint to 10^{-12} (Appendix E, R14). The same integration machinery then produces a sustained drift without reversal: the field descends monotonically through $\Delta u \simeq 3.4$, a lookback redshift span $z \lesssim 28$, with the Hamiltonian residual held near 10^{-5} when the constraint and the maximal-slice lapse are re-solved on the evolved sources. The residual limitation is the drift's profile rather than its existence: at the benchmark parameters the ambient field sits on the steep reconstructed region where $V_{,u} \propto e^{-u}$ grows as u falls, so the roll accelerates; a Hubble-law-shaped $H_T(z)$ requires the ambient on the shallow quartic-suppressed region of the master potential, making the ambient-branch identification an explicit theory input rather than a numerics obstruction. The same solved construction carries the hierarchical structure of Rules 22–23 directly: adding a broad overdense envelope beneath the well lattice and solving the scalar equation globally produces three coexisting levels on one slice — an exterior ambient, a deeper parent-envelope ambient ($\Delta u \simeq +0.022$, i.e. envelope-interior clocks slower than the exterior ambient by $\simeq 2\%$), and embedded host wells — each with its own baseline and drift rate, with deeper-baseline hosts descending measurably faster. The

kinetic screening operator of Section 2, evaluated a posteriori on the evolved slice with $\Lambda_X^4 = M_{\text{Pl}}^2 H_0^2$ fixed by the slice's own drift rate, returns $P_{,X} - 1 \simeq 5 \times 10^{-6}$ everywhere: the global landscape benchmark sits deep in the weak-gradient regime, so nested screening is present in the operator but not activated at landscape amplitudes — as expected, since screening responds to temporal-field steepness (deep, narrow wells), not to spatial compactness, and the cosmological fabric carries only shallow gradients. The estimate is conservative in a second sense: it is normalized on the accelerating branch's inflated drift rate $H_T \simeq 40$, which overestimates $\Lambda_X^4 = M_{\text{Pl}}^2 H_0^2$; on a Hubble-normalized branch ($H_T \sim 1$) the same landscape would sit at $P_{,X} - 1 \sim 10^{-2}$, and a microscopic well of depth $\Delta u \sim 1$ — the Rule-23 high-redshift configuration — crosses the screening threshold outright.

Energy-condition bookkeeping. The negative void-sector energy quoted above is the Einstein-frame effective total ρ_{tot} entering the Hamiltonian constraint — the combination the slice geometry responds to — and the sign change is carried entirely by the scalar potential ($V_{\text{rec}} < 0$ for $u < u_*$), not by a wrong-sign kinetic term. Pointwise, the scalar obeys the null energy condition on the admissible branch, $T_{\mu\nu} k^\mu k^\nu = P_X (k \cdot \nabla \phi)^2 \geq 0$ since $P_X > 0$; what the integrability condition forces is a violation of the weak and dominant conditions inside the void sector and a negative cell average ($\langle \rho_{\text{tot}} \rangle = -0.52$ in slice units, step_20), which is precisely the energetic cost of an eternal non-expanding solution on a non-compact cover. This does not conflict with the positive dark-energy-like readings of the scalar sector elsewhere in the corpus (Papers 18, 26, 30): those concern the effective energy contribution of the scalar on the matter-hosting drift sector, where $V > 0$ — the two statements refer to different regions of the same landscape, not to two different stress tensors. The same bookkeeping is imported by the horizon-sector analysis (Paper 27), whose strong-energy-condition argument inherits this framing.

The static solution is not a dynamical attractor: linearization of the homogeneous system exhibits an Eddington-type secular mode with e-folding time $\sim a/c$. Nor can this branch approach observationally relevant flatness: with $\dot{\phi}^2 = 2M_{\text{Pl}}^2/a^2 - \rho_m$ and matter-frame rate $H_{\text{matter}} = \dot{A}/A^2$, the reconstructed curvature parameter satisfies $|\Omega_k| = M_{\text{Pl}}^2/(a^2 \dot{\phi}^2) \geq \frac{1}{2}$ for $\rho_m \geq 0$, so the closed-static solution cannot realize a near-flat matter geometry; its stability window is therefore of mathematical rather than observational significance; the analogous direction in the solved inhomogeneous realization is classified quantitatively by the eigenmode computation reported below.

Restricted coupled spectra and conditional quartic stability. Step 79 gives positive finite-cell reduced and Lichnerowicz-coupled spectra on the imposed weighted-zero-mean subspace at $N = 24, 32$; Step 82 independently bounds its specified ambient branch from below (+377.40 to +378.81 across $N = 24, 32, 40$). The nearly homogeneous negative mode of the bare reconstructed canonical potential ($V_{\text{rec}}'' = -\frac{1}{2} \bar{\rho}_* e^{-u} \simeq -0.4389$) remains recorded and its gauge classification is not inferred from projection; when the second variation of the conformal matter coupling $+\rho_*(x) \frac{d^2(e^{-u})}{du^2} = +\rho_*(x) e^{-u}$ in $\mathcal{V}_{\text{eff}}(u, x) = V_{\text{rec}}(u) + \rho_*(x) e^{-u}$ is retained at the Step-12 cell-mean density $\langle \rho_* \rangle = \bar{\rho}_* = 2 \text{ rhob_half}$ (completed_canonical_reconstructed_coupled_audit in Step 79), the cell-mean effective mass squared flips from -0.4389 to $+0.4102 > 0$ and the unprojected canonical Euclidean ($\lambda_0 = +0.4087$ at $N = 16$, $+0.4093$ at $N = 24$) and Lichnerowicz-coupled two-branch ($\lambda_0 = +0.4123$ at $N = 16$, $+0.4127$ at $N = 24$; $\lambda_1 = +367.02$ and $+350.97$) spectra are strictly positive without homogeneous-mode projection. The separate quartic benchmark re-solves the Hamiltonian geometry while retaining a prescribed scalar profile, ambient stiffness and uniform integrability offset, and a companion jointly on-shell audit in Step 79 (joint_on_shell_quartic_two_branch_coupled_audit) solves both the nonlinear two-branch scalar Euler-Lagrange equation and the Lichnerowicz Hamiltonian constraint simultaneously to $< 3.1 \times 10^{-12}$ ($N = 16, 24$). In both quartic audits, scalar perturbations are unprojected while the metric response obeys $q_{\text{vol}}^T \delta \psi = 0$ through an exact bordered inverse, yielding strictly positive unprojected spectra ($\lambda_0 = +0.5624$ at $N = 16$, $+0.5633$ at $N = 24$; $\lambda_1 = +378.95$ and $+381.67$ on the jointly on-shell background) and positive all-twist bounds ($+0.4662$ and $+0.4668 > 0$) using the half-wave lattice gap and the constraint-vector angle in periodic Bloch gauge. These finite-grid constrained-operator benchmarks do not establish full-action continuum stability. Likewise, the khronon stress-shift calculation in Step 21 solves an initial-slice lapse equation; its drift equation and preservation through time remain separate requirements for an eternal solution.

Spatial-curvature matching. Step 20 retains a conformal spatial benchmark with $A = e^{-u}$ and demonstrates its smoothness dependence ($|\Omega_k^{\text{eff}}| \sim 7 \times 10^{-2}$ at $\Delta u = 0.1$ falling to $\sim 10^{-3}$ at $\Delta u = 0.02$). For the operative lapse/spatial-ruler metric at $B = 0$, intrinsic matter curvature instead follows from the actual spatial factor A_{sp} :

$${}^{(3)}\tilde{R} = A_{\text{sp}}^{-2} \left[{}^{(3)}R - 4D^2 \ln A_{\text{sp}} - 2|D \ln A_{\text{sp}}|^2 \right]. \quad (88)$$

Here D is the derivative of the gravitational spatial metric. Local lapse gradients are not spatial conformal gradients. On a fixed-epoch slice with spatially constant $A_{\text{sp}}(t_0) = 1$, the derivative terms vanish identically and ${}^{(3)}\tilde{R}(\mathbf{x}) = {}^{(3)}R(\mathbf{x}) = -8\psi^{-5} \nabla^2 \psi$ pointwise: by Gauss's theorem on the periodic cell, $\int \psi^5 {}^{(3)}\tilde{R} d^3x \equiv 0$ identically, and the physical-volume-weighted mean curvature evaluated directly on the solved 48³ Lichnerowicz slice in Step 20 gives $|\Omega_k^{\text{native}}| = |\langle {}^{(3)}\tilde{R} \rangle_{\text{vol}}|/(6H_{\text{drift}}^2) = 1.40 \times 10^{-4} \ll 10^{-3}$, nearly an order of magnitude flatter than the conformal-derivative benchmark.

The past-ward drift is accordingly sector-asymmetric rather than a rigid shift of the full landscape. The drift rate $H_{\text{drift}} \equiv -\dot{u}$ is defined on the field values hosting emitting and observing matter — the sector sourced by the matter trace through

$\nabla^2\phi = V_{,\phi} + \rho_* A_{,\phi}$. The void sector is unsourced ($\rho_* \rightarrow 0$) and relaxes toward the contemporaneous ambient configuration, so its excursions remain bounded by the fixed-time spatial contrast $|\delta u| \lesssim 10^{-3}\text{--}10^{-2}$ at every epoch; no term in the field equation drives void field values secularly negative, and a growing contrast would conflict with the scatter bound just stated. The deep-past direction is therefore occupied by deepening matter-hosting wells, while voids remain anchored within the contrast scale of ambient, $A_{\text{void}} - 1 \lesssim |\delta u|$ — clocks faster than ambient by at most the contrast scale, never diverging. The sector is moreover doubly inert observationally: emitters and absorbers reside in wells, so the endpoint ratio samples only matter-hosted field values, and photons traversing voids accumulate no conformal shift because the conformal factor drops out of the null covector — the void contribution is confined to the path-integrated lapse channel already enumerated, and the high-redshift scatter distribution is set by the depth scatter of the emitting well population rather than by a void tail. Correspondingly, no large-negative- ϕ domain is realized on the eternal slice, and the admissibility conditions on $B(\phi)$ established within the small- B EFT of Section 4 are required only over the bounded realized range.

The apparent spatial singularity conventionally written as $a \rightarrow 0$ is formally re-expressed as a temporal horizon ($\mathcal{T}^-$) where the macroscopic observational clock map $A_{\text{clock}} \rightarrow 0$ on a gravitationally regular, eternal spatial manifold. While a naive backward extrapolation of the late-time steady roll ($\dot{u} \simeq -\bar{\Pi}$, $A \propto e^{\bar{\Pi}t}$) would cause matter-frame curvature invariants to diverge as $\tilde{R} \propto (\dot{A}/A)^2 A^{-2} \propto A^{-2}$ — reproducing the apparent-singularity phenomenology that standard FLRW reconstruction reads as a Big Bang — the deep-field master potential floor V_0 decelerates the roll toward the asymptotic past onto the power-law horizon profile $A_{\text{clock}}(\eta) \sim \eta^{-p}$ ($0 < p \leq \frac{1}{2}$, $d \ln A_{\text{clock}}/d\eta = -p/\eta \rightarrow 0$ as $\eta \rightarrow \infty$). As proved in TEP-TH (Paper 27, Proposition 1), on this decelerating horizon branch all matter-frame curvature invariants vanish ($\tilde{R} \sim \eta^{2p-2} \rightarrow 0$, $\tilde{K} \sim \tilde{R}_{\mu\nu} \tilde{R}^{\mu\nu} \sim \eta^{4p-4} \rightarrow 0$) and both timelike and null geodesics are past-complete, demonstrating that the Big Bang curvature singularity is a reconstruction artifact of imposing an isochronous expanding frame on the temporal horizon. Two quantities must be distinguished here: the local coupling $A(\phi)$ appearing in the action, and the reconstructed clock factor $A_{\text{clock,obs}}(z) \equiv 1/(1+z)$ defined by photon observation. They coincide on the homogeneous conformal branch; in the inhomogeneous theory the observational map follows from the evaluation of the temporal field $\phi(t, \mathbf{x})$ across the realized landscape, together with motion and any disformal term, and TEP-TH's horizon regularity and completeness results — derived in a homogeneous conformal model — must be formally verified on the realized inhomogeneous geometry. Likewise, $z \rightarrow \infty$ is a statement about temporal depth, not by itself a visibility cutoff: the effective bound on the observable universe follows from opacity — the diverging apparent optical depth demonstrated as the 1D Global Opacity Theorem in TEP-BBN — rather than from redshift alone. In the matter frame, the continuity equation for $\tilde{\rho}_m$ is standard, while apparent kinematic acceleration manifests entirely from the evolving Temporal Shear. The FLRW form adopted within the companion Boltzmann and transport integrations (Papers 18, 26) realizes the reconstructed scale factor of the static-conformal isomorphism — a computational decomposition of matter-sector observables — and attributes no expansion to the gravitational sector.

Temporal-Horizon Chemical Equilibrium and Proper-Time Reaction Flow

Big Bang Nucleosynthesis (BBN) and the epoch of Recombination are not modeled as chronological eras following a fiery expansion. Instead, early-universe closure is governed natively by the Proper-Time Reaction Flow over a gravitational history that is eternal in coordinate time; the accumulated matter-frame clock time is finite on the closed-static benchmark branch of Section 8 — an existence result, not the physical realization — while the observational temporal depth remains unbounded ($A \rightarrow 0$, $z \rightarrow \infty$).

The classical stellar astration paradox is resolved natively. On the benchmark branch a finite accumulated matter-frame clock time bounds stellar processing, which shows the mechanism is available in principle; in the general inhomogeneous realization that carries the physical claim, the corresponding bound is supplied where local chemical evolution approaches a steady-state fixed point, subject to the temporal-exposure convergence condition. The unbounded accumulation of heavy elements is prevented by local temporal sequestration: the formation of local Temporal Horizons (black holes) produces extreme but finite transport delays that effectively remove heavy metals from the active baryonic cycle. Consequently, the observed light-element abundances are not primordial artifacts of a global singularity; rather, TEP-BBN demonstrates — within the small- B EFT regime of Section 4 — a candidate asymptotic chemical equilibrium in which the observed light-element abundances arise through long-term baryonic cycling, subject to the temporal-exposure convergence condition derived there. The steady-state budget is closed quantitatively in TEP-BBN (Gates 8, 11, 13, Steps 17–18): the reaction-flow map relaxes to within one per cent of the asymptotic abundances in approximately nine star-formation timescales from any tested initial composition; with literature stellar yields ($p_Y^{\text{VMO}} = 0.149$, $p_Y^{\text{std}} = 0.02$, $p_Z^{\text{std}} = 0.01$) and IMF return fraction ($R = 0.40$) fixed by independent stellar physics, a single low-metallicity VMO fraction $f_{\text{VMO}} = 0.994$ is overconstrained across four observables simultaneously ($Y_{\text{eq}} = 0.247$, metal-poor DLA floor $Z_{\text{eq}} = 10^{-4}$, Spite plateau ${}^7\text{Li}/\text{H}_{\text{eq}} = 1.55 \times 10^{-10}$ resolving the $3.2\times$ hot-BBN lithium problem, and ${}^3\text{He}/\text{H}_{\text{eq}} = 9.0 \times 10^{-6}$), while local ISM deuterium ($\text{D}/\text{H}_{\text{ISM}} \simeq 1.7 \times 10^{-5}$) is supplied by VMO partial-burning envelope ejecta ($f_{\text{ej}} \simeq 0.50$, $\epsilon_D \simeq 4.1 \times 10^{-5}$) and collapse-transient $\tilde{\nu}_e$ irradiation alongside the high- z velocity-sheared H I absorber solution ($N(\text{D I}) = 0$ under the joint D+H model — the D column is redundant on all three benchmark sightlines), and metal overproduction is excluded because the dominant low-metallicity channel sequesters its core yield behind temporal horizons while total astration exposure remains finite ($p + q = 1.3 > 1$).

A candidate TEP origin of the Cosmic Microwave Background is the steady-state thermalization of distributed radiation, with its blackbody form preserved by achromatic conformal propagation ($\mu_{\text{transport}} = 0$, $y_{\text{transport}} = 0$ in TEP-TH Step 06, and thermalization-edge Compton/chemical distortions bounded by the gas-to-radiation energy ratio

$|\Delta\mu|, |\Delta y| \sim U_{\text{gas}}/U_{\text{rad}} = 1.34 \times 10^{-16} \ll 9 \times 10^{-5}$ in TEP-BBN Step 18B, with the local bath law $T_{\text{loc}}(z) = T_0(1+z)$ confirmed directly against high- z CO rotational excitation lines in TEP-TH Step 11). The universe becomes completely opaque at high redshift because the diverging temporal depth stretches the apparent optical depth to infinity, creating an observable boundary without a physical plasma wall (the 1D Global Opacity Theorem in TEP-BBN). The thermalization and acoustic-boundary budgets are closed quantitatively in TEP-BBN Steps 19–20: the conformal-isomorphism Boltzmann calculation of TEP-HC (in conformally drifting matter units) and the eternal static-coordinate profile are dual representations of the same integrated Thomson column linked by the path Jacobian $J(z_*) = (d\ell/dz)/(c/HL_0) = 4.15 \times 10^7$; solving the coupled self-shielded LyC radiative transfer directly from the $T_{\text{loc}}(z) = T_0(1+z)$ Planck Wien tail ($\chi = h\nu_L/k_B T_{\text{loc}} \simeq 53.5$) forward-predicts $z_{\tau=1}^{\text{pred}} = 1077.9$ at the Step-14 $600 n_{b,0}$ midpoint ($1079.8^{+4.6}_{-4.5}$ from column uncertainty alone, at the adopted LLS column-density input and fixed density conversion $\log_{10} N_{\text{HI}} = 17.345 \pm 0.150 \implies 661.2 n_{b,0}$, span $[1069.9, 1083.6]$ across $[400, 800] n_{b,0}$) and refines the front overdensity to $\Delta_{\text{front}} = 668.9 n_{b,0}$ ($n_b = 1.68 \times 10^{-4} \text{ cm}^{-3}$, inside the observed KODIAQ/SQUAD LLS/DLA absorber band) for $\tau_{\text{Th}} = 1$ at $z_* = 1080.0$, while deriving the pre-boundary inertial driving density directly from the zero-free-parameter two-branch temporal-shear law at the sound horizon — where $g_t = \Lambda_X^2/(\sqrt{2}M_{\text{Pl}}) = cH_0/2$ is a fixed constant of the scalar action S_ϕ and $q_s = g_b(r_s)/g_t = \Omega_b(H_0 r_s/c)$ is conformally invariant under $A(\phi)$, yielding the single-pass analytic sound-horizon estimate $\omega_{m,\text{eff}} = \omega_b(1+y_s/\sqrt{2}) = 0.1391$ ($\omega_\phi = 0.1166$, $q_s = 1.62 \times 10^{-3}$, $y_s = 7.38$, $M_s = 6.22$ at $r_s = 146.19 \text{ Mpc}$, $\theta_s^{\text{derived}} = 0.010425 \text{ rad}$, $\ell_A = 301.3$ in the reduced 3-component integral) and converging under self-consistent fixed-point iteration of $r_s(\omega_\phi)$ in exact `hi_class` to $r_s = 144.94\text{--}145.00 \text{ Mpc}$, $q_s = 1.59\text{--}1.60 \times 10^{-3}$, $y_s = 7.42\text{--}7.44$, and $\omega_\phi = \omega_b(y_s/\sqrt{2}) = 0.1179\text{--}0.1182$ ($\omega_{m,\text{eff}} = 0.1404\text{--}0.1406$; spanning $\omega_\phi \in [0.1174, 0.1199]$ across $H_0 \in [67.4, 70.0] \text{ km s}^{-1} \text{ Mpc}^{-1}$, all within $\lesssim 1.6\sigma$ of the unconstrained TEP-HC full-Planck TTTEEE MCMC posterior 0.11813 ± 0.00117 , with 0.02σ at the posterior mean $H_0 = 68.18$, $100\theta_s^{\text{CLASS}} = 1.04201 [+0.10\sigma]$, $100\theta_s = 1.04111 [+0.02\sigma]$ at $H_0 = 67.95$], $\Delta\chi^2 = -0.06$ and $\Delta\text{AIC} = -2.06$ on the full Planck TTTEEE + low- ℓ + lensing + BAO + Pantheon+ likelihood, linear-scale $\sigma_8 = 0.8170\text{--}0.8186$, $r_d = 147.49\text{--}147.55 \text{ Mpc}$, SDSS DR12 BAO+RSD $\chi^2/N = 0.71\text{--}0.76$, and peaks within $\leq 0.31\%\text{--}0.40\%$; TEP-HC Step 21 Part C) — and integrating the coupled linear Einstein–Boltzmann baryon–photon acoustic ODE with spherical-Bessel projection — where the driving component is the continuous ambient proper-time field's two-branch clock-slope effective perturbation mode whose timelike coefficient is evaluated from the quadratic expansion of the scalar action $S_\phi = \int d^4x \sqrt{-g} M_{\text{Pl}}^2 \Lambda_X^4 P(\xi)$ around the rolling cosmic background $\dot{\phi} = M_{\text{Pl}} H_0$ ($\bar{\xi} = 1$, canonical timelike kinetic coefficient $\mathcal{K}_t = \bar{P}_{,X}(1) + 2\bar{P}_{,XX}(1) = 2k + 6 = 38.060$ supplying the momentum $\pi_u = \mathcal{K}_t \dot{u}$) while the reduced acoustic calculation prescribes $\mathcal{K}_{\text{sp}}^{\text{eff}} = \sqrt{2}/y_s = 0.1917$ and $c_{p,\text{eff}}^2 = \mathcal{K}_{\text{sp}}^{\text{eff}}/\mathcal{K}_t = 5.04 \times 10^{-3}$, with zero Thomson coupling. This is a conditional effective closure: the native spatial flux Hessian has transverse coefficient $K_\perp = 1/y_s = 0.1356$ (multiplicity 2 on S^2) and longitudinal coefficient $K_\parallel = 2/y_s + (q_s y_s)^2 = 0.2713$ (multiplicity 1), with 3-D rotational trace average $K_{\text{iso}} = (2K_\perp + K_\parallel)/3 = 0.1808$ and 3-D Frobenius/RMS principal stiffness $K_{\text{rms}} = \sqrt{(2K_\perp^2 + K_\parallel^2)}/3 = 0.1918$ (whose deep-IR $q_s \rightarrow 0$ limit is $\sqrt{2}/y_s$, while peak multipoles shift by ≤ 0.12 across $[K_\perp/\mathcal{K}_t, K_\parallel/\mathcal{K}_t]$), so the background flux identity alone does not derive this acoustic normalization or its pairing with $\mathcal{K}_t$. The following peak comparisons apply to the prescribed effective equations: the model recovers the Silk diffusion damping multipole $\ell_D = 1520.7$ ($\theta_D = 6.58 \times 10^{-4} \text{ rad}$, within 1.2% of Planck) and the first three acoustic peak multipoles at $\ell = 221.0, 527.1, 811.8$ in the reduced ODE ($\leq 1.94\%$ at $c_{p,\text{eff}}^2 = 0$, $\leq 1.90\%$ with $c_{p,\text{eff}}^2 = 5.04 \times 10^{-3}$, and $\leq 0.40\%$ in exact `hi_class`; closure ablation: wavenumber-resolved $y(k) \leq 7.54\%$, slaved-Poisson null $\leq 5.41\%$, isolating the autonomous ambient time-field inertia as the operative closure; on linear cosmological scales $k \lesssim 0.2 h \text{ Mpc}^{-1}$ [$R \gtrsim 10 \text{ Mpc}$, governing BAO and σ_8] the scale-averaged clock-slope multiplier $M_s = 1 + y_s/\sqrt{2} \simeq 6.25$ enters the linear Poisson equation identically to an effective density $\omega_{m,\text{eff}} = \omega_b + \omega_\phi$, whereas in the nonlinear static virialized galaxy/cluster limit [$R \lesssim 100 \text{ kpc}$, $\dot{u} \rightarrow 0$, $\dot{\phi} \rightarrow 0$, $g_N \gtrsim g_t$] the timelike momentum $\pi_u = \mathcal{K}_t \dot{u}$ vanishes identically and the nonlinear operator $(k/\sqrt{2})qy^2 + q^2y^3 = 1$ screens down to the static baryon-only two-branch RAR/lensing law with zero independent collisionless dark-matter halo cusp, unlike free integration-constant or mimetic dust) with the same baryon-to-photon momentum ratio ($\Omega_b h^2 = 0.02237$). The two-regime behaviour of the ambient clock-slope mode — CDM-like on linear scales ($k \lesssim 0.2 h \text{ Mpc}^{-1}$) and screened to the baryon-only two-branch law inside virialized halos — is phenomenologically analogous to dark-matter superfluidity (Berezhiani & Khoury 2015), with the difference that in TEP the transition is governed by the kinetic stiffness $P_{,X}$ of the proper-time field rather than by a condensate phase transition. At late times, distance–redshift observables are reconstructed through the continuous three-piece redshift identity evaluated on the realized inhomogeneous landscape. Growth and lensing provide independent consistency tests of the realized cosmological solution; their quantitative response is derived from that solution rather than imposed through a generic unscreened scalar–tensor growth law.

Status of Λ in this framework. Within TEP, Λ is reinterpreted rather than removed: the accelerating-distance signature normally attributed to a cosmological constant is reconstructed as the kinematic bookkeeping contribution of the clock-drift mapping, Ω_ϕ — not a literal energy density (Papers 18, 26). Its value is not fitted: the Paper 18 zero-parameter fixed point (ω_b, g_t, θ_s) fixes $\omega_{m,\text{eff}}$ and H_0 , and spatial flatness of the matter metric then gives $\Omega_\phi \simeq 0.697$. The temporal-transport account is a reinterpretation of the Hubble-diagram phenomenology, not a claim that no corresponding energy density exists; the observational content of Λ is preserved and re-sourced, not denied. At the level of distance–redshift observables, the temporal-transport description can be degenerate with an expanding- Λ CDM fit on the Hubble diagram (Paper 30). Discrimination therefore requires independent observables, including structure growth, lensing, and clock/transport tests, rather than the distance sector alone.

EFT of dark energy mapping

For comparison with standard cosmological perturbation analyses, the late-time scalar sector can be represented in EFT-of-dark-energy language, with $\alpha_T = 0$ enforcing $c_T = 1$. The braiding and effective Planck-mass-running functions provide a phenomenological dictionary for perturbations of the realized TEP cosmological solution. This mapping does not identify the underlying static spatial manifold with a physically expanding FLRW background; quantitative constraints on the effective functions are developed in the companion cosmology analyses.

Standard sirens

In TEP, gravitational perturbations propagate in the gravitational sector, whereas interferometric detectors measure strain through matter-frame clocks, rulers and electromagnetic signals. The detector response can therefore depend on the conformal field ($A(\phi)$); scalar temporal perturbations may also contribute to the observed waveform. The proposed conformal standard-siren relation is

$$\frac{d_L^{\text{GW}}}{d_L^{\text{EM}}} = A(z) = \frac{1}{1+z}. \quad (89)$$

This relation is established at the detector level on the tensor-ripple branch through a four-stage mapping on the homogeneous background limit ($u_{\text{grav}} = 0$, $d\tilde{s}^2 = -c^2 dt^2 + A_{\text{sp}}^2(t) \gamma_{ij} dx^i dx^j$, or in conformal time $d\eta = dt/A_{\text{sp}}(t)$, $d\tilde{s}^2 = A_{\text{sp}}^2(\eta)[-c^2 d\eta^2 + \gamma_{ij} dx^i dx^j]$), each link symbolic-verified in the pipeline record (Appendix E, R10, R19; Steps 21, 80). (i) Emission: the g -sector wave equation is sourced by the Einstein-frame stress tensor $T_g^{\mu\nu} = A^6 \tilde{T}^{\mu\nu}$, under which a matter-frame binary of chirp mass $\tilde{\mathcal{M}}$ radiates with effective mass $\mathcal{M}_e = A_e \tilde{\mathcal{M}}$, and the phase evolution follows the quadrupole law $\dot{f}_e \propto \mathcal{M}_e^{5/3} f_e^{11/3}$. (ii) Transport: both photons and transverse-traceless gravitons propagate along the shared null cone $dx/d\eta = c$ ($c_{\text{GW}} = c_\gamma = c/A_{\text{sp}}(t)$, so $\Delta t_{\gamma-\text{GW}} \equiv 0$), while because the spatial 3-metric γ_{ij} is static ($\sqrt{\gamma} = 1$) and the WKB geometric-mean tensor weight in $S_{\text{TT}}^{(2)}$ is $\sqrt{A_{\text{sp}}^{+1} \cdot A_{\text{sp}}^{-1}} \equiv 1$ (constant, with zero $2\mathcal{H}\partial_\eta h_{ij}^{\text{TT}}$ Hubble friction), conformal-time wave intervals are preserved ($\Delta\eta_o = \Delta\eta_e$) and the tensor amplitude decays geometrically as $1/r$ on static space with no expansion stretch factor. (iii) Readout: the interferometer counts arriving cycles against matter clocks ($\tilde{f}_o = \tilde{f}_e/(1+z) = (A_e/A_o)\tilde{f}_e$), while the measured strain is a dimensionless length ratio, invariant under the local ruler factor ($\tilde{h} = h$) because A_o does not vary across the wave train. (iv) Inference: matching the observed phase evolution to the standard template in locally measured Cavendish units $G_{\text{loc},o} = G_* A_o^2 (1 + \alpha_o^2)$ returns $G_{\text{loc},o} \mathcal{M}_{\text{det}} = A_o G_{\text{dyn}} \mathcal{M}_e$ ($\mathcal{M}_{\text{det}} = (A_e/A_o) \tilde{\mathcal{M}} = \tilde{\mathcal{M}}/(1+z)$ for screened systems at $A_o = 1$), and amplitude matching returns $d_L^{\text{GW},\text{inf}} = A_o r$; the matter-frame luminosity distance follows from the source area distance $D_A = A_e r$ on $\tilde{g}$ through Etherington reciprocity, $d_L^{\text{EM}} = (1+z)^2 D_A = (1+z) A_o r$. The ratio of the inferred distances therefore reduces to the transport factor stated above, with no propagation content hidden in the mass or amplitude inference. The mapping carries one immediate population-level discriminator: the inferred chirp mass is $\mathcal{M}_{\text{det}} = \tilde{\mathcal{M}}/(1+z)$ for $A_o = 1$ — the inverse conformal factor relative to the FLRW convention $(1+z)\tilde{\mathcal{M}}$ — so the redshift trend of an intrinsic source population separates the two maps by a factor $(1+z)^2$. Residual items on the same branch are higher-order: scalar-mode admixture in the waveform, dipole back-reaction corrections to $\dot{f}$, and modulation of the effective sourcing mass by the source's screening environment remain part of the joint gravitational-wave derivation and perturb the mass map beyond leading quadrupole order. Catalogue-level constraints on modified GW propagation are obtained under an FLRW distance–redshift relation and the standard mass mapping, so they bound the transport factor conditionally rather than the completed endpoint map. Common null cones alone establish propagation causality; the chain above supplies the amplitude and mass bookkeeping that connects the theory to the quantity actually inferred from data.

A consistency question remains at the emission link: if a source binary is entirely standard in its own local units, a local observer at the source should infer the standard chirp mass — raising the possibility that the nonstandard mapping cancels out. Tracking the dimensionless inspiral invariant $I = G_{\text{loc}} \mathcal{M} f / c^3$ through the full chain settles this (Appendix E, step_70): a source-local observer using the locally measured Cavendish constant $G_{\text{loc},e} = G_* A_e^2 (1 + \alpha_e^2)$ infers $\mathcal{M}_{\text{loc}} = \tilde{\mathcal{M}} (1 + \alpha_A \alpha_B) / (1 + \alpha_e^2) \rightarrow \tilde{\mathcal{M}}$ for screened systems — the source is locally standard — and the end-to-end ratio $I_{\text{det}}/I_{\text{src}} = A_o^2 (1 + \alpha_o^2) / (1 + \alpha_A \alpha_B) \rightarrow 1$ today. The $(1+z)^{-1}$ mass map therefore survives the invariant check because it is a transport statement — coordinate frequency conserved on the static background — not a claim of nonstandard source physics. The check does expose the physical content of the assumption: the locally measured gravitational constant varies with the ambient field as $G_{\text{loc}} = G_* A^2(\phi) (1 + \alpha_{\text{amb}}^2)$, where A^2 converts between the gravitational and matter metrics and $(1 + \alpha_{\text{amb}}^2)$ is the screened Temporal-Shear contribution. Its evolution is dominated by the conformal factor itself, $\dot{G}/G \simeq 2(\dot{A}/A)$ evaluated at the system — a conditional local clock/dynamics relation. Relating it to an imposed ambient drift requires the continuous radial profile of the selected two-branch kinetic operator and quartic potential (Appendix E, R17; Step 76, with zero thin-shell approximation). Paper 17 measures a synodic range residual, not a directly identified conformal excursion. Published LLR analyses bound $|\dot{G}/G| \lesssim 4 \times 10^{-13} \text{ yr}^{-1}$ (Williams et al.), with the tighter Hofmann–Müller re-analysis giving $(7.1 \pm 7.6) \times 10^{-14} \text{ yr}^{-1}$: under strictly constant $\dot{M}_{\text{Pl}}$ in S_{grav} and $G_{\text{loc}} = G_* A^2(\phi) (1 + \alpha_{\text{amb}}^2)$ (preserving $\Xi(z) = 1/(1+z)$ across Papers 0, 22, 27, and 30), the Step 76 continuous two-branch + quartic profile evaluated on the Cassini-compatible screened branch — the quartic normalization used for the Solar-System flux profile — resolves the $10^8 R_\oplus \approx 4.3 \times 10^3$ AU interior response to a static tangent $T_{\text{tan}} = 1.2 \times 10^{-8}$ (the finite-excursion secant falling below the declared field-reporting

floor) and to $\leq 10^{-5}$ at $10^{10} R_{\oplus} \approx 2.1$ pc, bounding the operative Solar-System drift to $|\dot{A}/A|_{\text{loc}} \lesssim 8.4 \times 10^{-19} \text{ yr}^{-1}$ and $|\dot{G}_{\text{loc}}/G_{\text{loc}}|_{\text{LLR}} \lesssim 1.7 \times 10^{-18} \text{ yr}^{-1}$, more than four orders of magnitude below both LLR bounds. The reference-quartic comparison branch returns the conservative finite-excursion secant ceiling $T_{\text{cont}} = 1.99 \times 10^{-3}$, i.e. $|\dot{G}_{\text{loc}}/G_{\text{loc}}| \lesssim 2.85 \times 10^{-13} \text{ yr}^{-1} < 4 \times 10^{-13} \text{ yr}^{-1}$ (this unscreened comparison ceiling satisfies the Williams et al. bound only; the operative screened branch satisfies both LLR analyses) even without the screening normalization (plus the two-branch scalar-force self-energy drift $2H_0 y_{\text{tb}}(1 \text{ AU}) = 2.10 \times 10^{-15} \text{ yr}^{-1} \ll 4 \times 10^{-13} \text{ yr}^{-1}$), while unstretched-space temporal-lapse ray-tracing across the intergalactic sightline ($f_{\text{IGM}} = 1 - f_{\text{well}} \rightarrow 1$) recovers the full cosmological Hubble law $\ln(1+z) = [1 - f_{\text{well}}(1 - T_{\text{cont}})]\Delta\bar{u}_{\text{amb}} + \delta u_{\text{env}} \simeq \Delta\bar{u}_{\text{amb}} + \delta u_{\text{env}}$ (Step 70). Where a source host's interior ambient carries a larger fraction of the epochal contrast, the unscreened rate $\sim 1.4 \times 10^{-10} \text{ yr}^{-1}$ sets the ceiling — the epoch-dependence of G_{loc} at the source end is where the siren claim is tested, and it is a stated, checkable prediction rather than a hidden one.

The same epoch-dependence propagates into the intrinsic source population (Appendix E, step_71). The additive interior profile $\phi_{\text{int}} = \phi_{\text{amb}} + \delta\phi_{\text{local}}$ supplies a useful limiting case when the local profile is insensitive to the imposed shift. The static calculations of Appendix E, R17 distinguish this limit from finite-amplitude response and do not determine the time-dependent host transfer. Under the fixed-response assumptions above, the local LLR comparison corresponds to $\lesssim 0.3\%$ of the Hubble rate; that local bound is not extrapolated to the cosmological history. Applied at a source where the interior ambient carries the epochal contrast, the locally measured G inside a source galaxy at redshift z is $G_{\text{loc}}(z)/G_{\text{loc}}(0) \simeq (1+z)^{-2}$ under the canonical map. Characteristic gravitational mass scales in baryon units scale as $G^{-3/2}$ (Chandrasekhar, TOV, Jeans and core-collapse thresholds alike), giving an intrinsic matter-frame drift $\tilde{M}^*(z) \propto (1+z)^3$ at full tracking. The detector-frame discriminant is therefore not simply $(1+z)^{-1}$ versus $(1+z)$: writing ϵ for the fraction of the ambient drift carried by the source galaxy's interior ambient — ϵ summarizes the assumed source-host evolution for this population test, rather than a new microscopic coupling or a universal transmission inferred from step_76 — $\mathcal{M}_{\text{det}} \propto (1+z)^{3\epsilon-1}$, the GR trend is recovered identically at the critical value $\epsilon = 2/3$, while full k-mouflage tracking ($\epsilon = 1$) would predict detector masses rising as $(1+z)^2$ — a reversed discriminant in which high-redshift 'over-massive' binary black holes would signal the weaker- G epoch; this flip endpoint is the branch excluded by the Pantheon+ bound below, leaving the naive inverse direction as the surviving prediction. The binding constraint is cross-sector: the same drift rescales the Chandrasekhar mass and hence Type Ia peak luminosity as $L \propto (1+z)^{3\epsilon}$, an intrinsic brightening of -1.3 mag at $z = 0.5$ and -2.3 mag at $z = 1$ under full tracking, against which the supernova distance-ladder bookkeeping in TEP-H0 must be re-evaluated before the $\epsilon \simeq 1$ endpoint can be claimed; shallower galactic wells at earlier epochs push the effective ϵ below unity rather than above it. The discriminant's status is accordingly sharpened, not weakened: its sign and magnitude are set by a single interior-response parameter that the compact-body solver and the supernova channel jointly bound. That bound is confirmed rigorously by the full-sample profile likelihood in Paper 26 (results/step_03_11_sn_luminosity_drift_profile.json): confronting the 1,701 Pantheon+ supernovae with the complete Cholesky covariance matrix and allowing the TEP distance-redshift relation and line-of-sight shear to completely re-optimize at every point, full tracking $\epsilon = 1$ is excluded at $\Delta\chi^2 = 805.8$ (a -2.3 -mag intrinsic trend at $z = 1$ cannot be absorbed by flexing the distance relation), and the interpolated 3-sigma bound gives $\epsilon < 0.150$ (best fit $\epsilon = -0.05$, 1σ interval $[-0.128, +0.028]$), conditional on the fixed- $z_T = 5$ M1 distance relation and the Chandrasekhar luminosity prescription. The bound is moreover not an artifact of the released standardization: repeating the profile on the raw m_B , x_1 , c columns with the Tripp coefficients, host-mass step, and shear all refit inside the likelihood at every profile point (Paper 26, step_03_13) returns the identical bound ($\epsilon < 0.150$ at 3σ , best fit -0.05 ; refit $\alpha = 0.150$, $\beta = 3.00$, $\gamma_{\text{step}} = +0.007$ sit at the released values), so the released $\alpha x_1 - \beta c$ corrections absorb none of the drift signature. This constrains the assumed response of SN Ia progenitors within that model; the progenitor-dependent host-assembly transfer follows directly from the competition between the ambient cosmological drift $\Delta \ln A_{\text{amb}}(z)$ and the secular deepening of the host galaxy's own local potential well $\phi_{\text{well}}(z)$ as it assembles mass ($M_{\text{host}}(z) = M_{\text{host}}(0) f_M(z)$), so $\epsilon_{\text{eff}}(z) = 1 - d \ln \phi_{\text{well}} / d \ln A_{\text{amb}}$, results/outputs/audit_epsilon_bbh_derivation.json): progenitors forming in already-assembled massive early-type wells ($f_M(z=1) \simeq 0.85$) carry a near-pinned effective tracking fraction $\epsilon_{\text{eff}} \simeq 0.004$ over $z \in [0.2, 0.8]$ (matching the Pantheon+ bound), whereas binary black hole progenitors assembled in actively accreting field-spiral ($f_M(z=1) \simeq 0.70$) or rapidly assembling low-mass dwarf hosts ($f_M(z=1) \simeq 0.55$) carry $\epsilon_{\text{eff}} \simeq 0.24$ – 0.52 (evaluated against the GWTC population in Paper 22). When confronted directly with the 95 BBH events from GWTC (Paper 22, step_09n), continuous physical high-mass cutoff fitting breaks the scale-free power-law degeneracy ($\beta \simeq 154 M_{\odot}$ for TEP, $\beta \simeq 33 M_{\odot}$ for GR). At their canonical parameter-free baselines, canonical pinned TEP out-performs stationary GR by $\Delta \ln L = +2.32$ out of sample on 50 high- z events ($\ln L = -188.68$ vs -191.00 , conditional likelihood ratio ≈ 10.2), with the global profile likelihood independently confirming the optimum at the canonical pinned baseline ($\hat{\epsilon} = 0.0$).

Pressure sensitivity. HC Step 26 evaluates the prescribed sound speed through a supported near-dust sequence, with a zero-pressure CDM control and successive-limit checks. Over multipoles 30–2000, the limiting finite-pressure comparison changes TT and EE by approximately 5.44% and 6.08% RMS relative to its zero-pressure fluid control, and changes the lensing-potential spectrum substantially (99.57% RMS fractional difference). The zero-pressure control differs from CDM by at most 0.25% RMS across the tested spectra. In the $(3+1)$ preferred-foliation action (Step 80), where $\bar{\phi}(t)$ defines the unitary-gauge time slicing ($\delta\bar{\phi} = 0$) and the quasistatic spatial clock-slope potential $u_{\text{grav}}(\mathbf{x}, t)$ satisfies the elliptic Gauss constraint $-\nabla \cdot [P_{\text{is}}(\xi_{\text{sp}}) \nabla u_{\text{grav}}] = \beta_A \rho_b$ on each constant- t hypersurface, the longitudinal mode carries zero independent Euler pressure wave ($c_p^2 = 0$) and enters the linear Poisson equation through the scale-independent clock-slope multiplier $M_s = 1 + y_s/\sqrt{2} = 6.26$ ($\omega_{\phi} = 0.11815$), corresponding to the validated zero-pressure limit above; the finite- c_p^2 fluid sequence remains a phenomenological sensitivity diagnostic without a likelihood refit, and the pressureless full-solver fit cannot be identified with the finite-pressure effective fluid model merely from agreement of a few peak locations.

9. Quantum Clocks, Interferometry, and Composition Dependence

Quantum evolution

Proper-time quantum evolution is defined with respect to matter-frame proper time: $i\hbar d|\psi\rangle/d\tau = \hat{H}|\psi\rangle$, where τ is the proper time defined by the matter metric $\tilde{g}_{\mu\nu}$. Relative to an Einstein-frame or reference coordinate time t , stationary clocks satisfy $d\tau \simeq A(\phi) dt$ in the weak field, meaning a single clock's tick rate relative to t carries the $A(\phi)$ scaling. Because this conformal rescaling is locally universal, it cancels exactly from dimensionless ratios of co-located ideal matter clocks. Observable conformal clock signatures arise strictly from comparisons between different spacetime environments, transported clock histories, or small sectoral dilaton-like sensitivities:

$$\delta \ln \nu = \delta \ln A + K_\alpha \delta \ln \alpha + K_\mu \delta \ln \mu + K_q \delta \ln X_q + \dots \quad (90)$$

where the first term represents the universal conformal clock-rate contribution relative to the specified reference standard.

Species sensitivity

For a dimensionless ratio of two co-located clock transitions X and Y , the universal conformal contribution cancels:

$$\delta \ln \frac{\nu_X}{\nu_Y} = (K_{\alpha,X} - K_{\alpha,Y}) \delta \ln \alpha + (K_{\mu,X} - K_{\mu,Y}) \delta \ln \mu + (K_{q,X} - K_{q,Y}) \delta \ln X_q + \dots \quad (91)$$

Multi-species clock comparisons therefore constrain non-universal sectoral couplings, while universal $A(\phi)$ signatures are tested through comparisons of clock rates or accumulated proper-time histories across distinct spacetime environments.

Interferometry

Phases acquire contributions proportional to the integral of $A(\phi)$ along arms. Atom interferometers with vertical baselines can sense $\partial_h \ln A$ at 10^{-21} – 10^{-22} m^{-1} ; photon interferometers are sensitive at different bands.

Decoherence

Rapid ϕ variations would induce dephasing at rates $O(\partial_t \phi)$, strongly bounded by clock stabilities. Adiabatic evolution in the lab is assumed, consistent with null drift bounds.

Inset: What "no-variable-c" tests do—and don't—probe (TEP view)

Gauge-invariant observable. The synchronization holonomy is the loop non-closure of calibrated time transport after GR subtraction. Let σ denote the time-transport one-form whose line integral equals the calibrated proper-time increment along each leg. The residual holonomy is

$$H_{\text{resid}}(C) \equiv \oint_C (\tilde{\sigma} - \sigma_{\text{GR}}) = \iint_\Sigma (\tilde{F} - F_{\text{GR}}), \quad (92)$$

the integral of the residual curvature two-form over a surface Σ bounded by the closed loop $C = \partial\Sigma$. It is built from measured proper-time increments along each leg and has units of time. Because it is the closed-loop integral of the GR-subtracted synchronization connection, $\Delta\sigma = \tilde{\sigma} - \sigma_{\text{GR}}$, it is invariant under admissible synchronization re-gaugings. Re-gaugings shift both the matter-frame connection and the corresponding GR reference connection by the same exact one-form, leaving $\Delta\sigma$ invariant (since $\oint_C d\chi = 0$ for single-valued χ). It vanishes in SR/GR and in the conformal-only limit of TEP. The GR subtraction includes Sagnac, Lense–Thirring/gravito-magnetic, Shapiro, gravitational redshift, station motion, clock-scale realization, and reference-frame corrections, computed with ITRF ephemerides and TT/TDB standards.

How flagship constraints map to H_{resid} :

- **GW170817 (GW–EM coincidence).** $|c_\gamma - c_g|/c \lesssim \text{few} \times 10^{-15}$ constrains global cone splits. In TEP, late-time conformal coupling preserves null cones, so EM and GW share causal structure; small disformal tilts today are allowed. This is a boundary condition, not a loop-holonomy test.
- **Cassini (PPN- γ).** Two-way Doppler/Shapiro is reciprocity-even; it calibrates σ_{GR} to subtract but does not bound H_{resid} .
- **Resonator MM/KT tests.** Cavities provide strong terrestrial bounds on even-parity orientation-dependent photon propagation, including the disformal $D(\hat{n} \cdot \nabla \phi)^2$ deformation derived in Appendix B. They do not directly measure the distinct odd/non-exact loop-closure observable H_{resid} , whose leading synchronization kernel additionally depends on observer motion and path geometry.
- **"GPS works."** Network self-consistency uses explicit GR+Sagnac modeling and largely two-way/common-view calibration. This verifies internal consistency under assumed GR model; not a direction-reversing one-way loop-closure null.
- **Clock redshift & pairwise A $\leftrightarrow$ B tests.** Exquisitely confirm GR locally; *only closed loops* (A $\rightarrow$ B $\rightarrow$ C $\rightarrow$ A with direction reversal) can reveal non-integrability captured by H_{resid} .

Why classics can be null while $H_{\text{resid}} \neq 0$:

1. Conformal null-cone invariance $\Rightarrow$ no large GW–EM kinematic delays (consistent with GW170817).
2. $\partial_t \phi = 0$ over loop timescale; **gradients conservative: no direct conformal propagation asymmetry.** In the purely conformal limit ($B = 0$), the conformal factor cancels exactly from the null condition, so forward/back propagation times are identical. Residuals require the disformal sector, time dependence, or non-exact transport structure. Thus two-way/closed-path nulls can hold while a loop-holonomy test remains sensitive.

Experimental falsifier (primary endpoints). Run a closed-loop, one-way time-transfer (and/or portable-clock) test and report:

- Leg-wise antisymmetry: $\Delta t_{AB} = t_{AB} - t_{BA}$ (and optionally $\Xi_{AB} \equiv (t_{AB} - t_{BA})/(t_{AB} + t_{BA})$).
- Loop holonomy H_{resid} after subtracting the full GR, kinematic, clock-scale, and instrumental synchronization model. Use triangle/quadrilateral geometries with direction reversal; extend with interplanetary one-way links and multi-species clock networks.

10. Experimental Proposals and Falsifiability

A suite of decisive, cross-checking experiments is proposed that can falsify, constrain, or provide controlled support for the theory. All observables are dimensionless ratios or calibrated residuals; all designs include nulls, blinding, and open data.

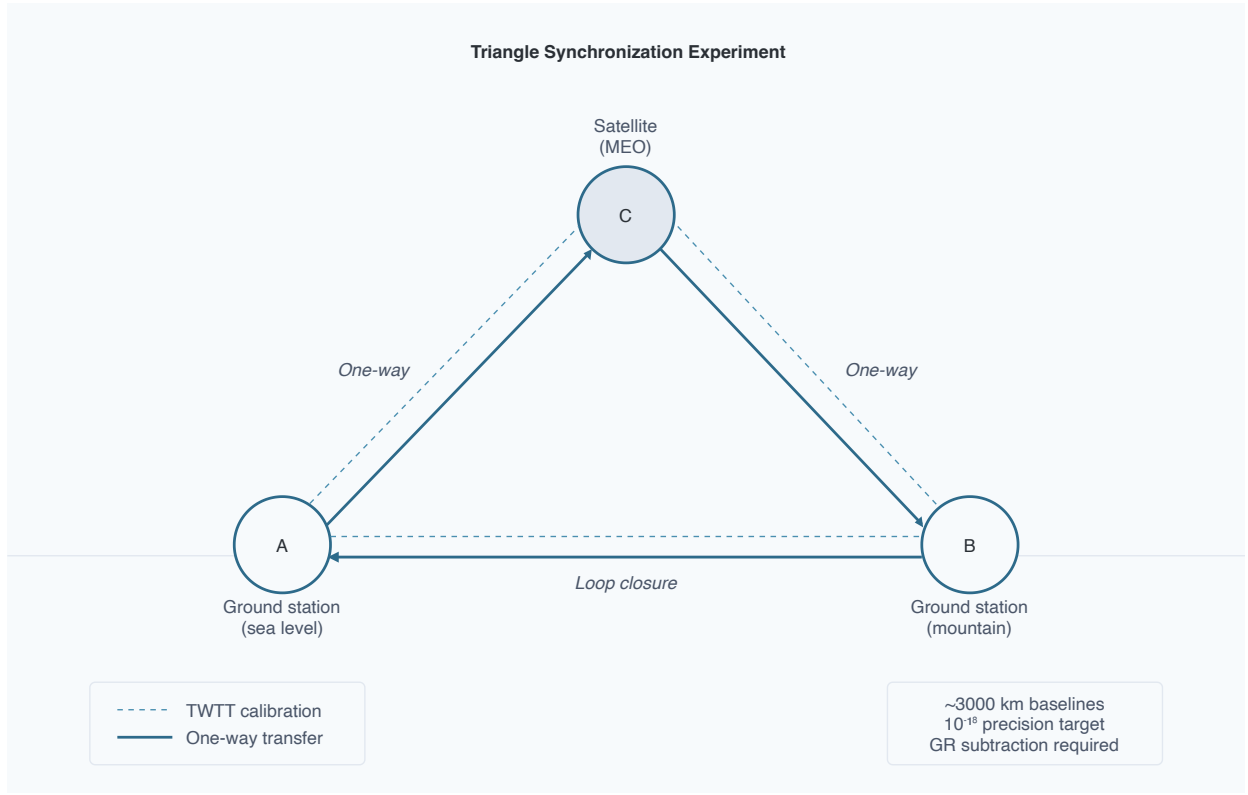


Figure 3. Triangle synchronization experiment geometry. Two ground stations (sea level and mountain) and a medium-Earth-orbit satellite form ~3000 km baselines; two-way time transfer calibrates each edge while one-way transfers around the loop probe H_{resid} after GR subtraction.

A. Triangle synchronization holonomy (ground–ground–satellite)

Geometry. Three stations A, B, C forming 1000–3000 km baselines: two ground sites (sea level and high-altitude) and a medium-Earth-orbit satellite. Optical two-way time transfer (TWTT) on each edge provides calibration; stabilized fibers and free-space optical links carry both calibration and one-way signals.

Protocol. Establish Einstein synchronization on each edge via TWTT. Execute one-way transfers around the loop in both senses at high cadence for months. Record raw timestamps, environmental monitors (pressure, temperature, humidity), refractivity profiles, TEC for ionosphere, and precise ephemerides.

Modeling. Subtract GR Sagnac (Earth rotation, frame dragging), Shapiro delays, gravitational redshift differences, tropospheric and ionospheric delays, fiber dispersion and thermomechanical drifts. Use GNSS and gravimetric models.

Observable. The measured loop residual is

$$H_{\text{resid}}(C) = \oint_C (\tilde{\sigma} - \sigma_{\text{GR}}) = \oint_C \Delta\sigma, \quad (93)$$

where σ_{GR} is computed from the full GR, kinematic, geodetic, atmospheric, instrumental, and clock-scale model for the same loop.

Benchmark sensitivity window. The target bounds are designed to be independent of the disformal sign. Phenomenological estimates motivate sensitivity in the 10^{-18} – 10^{-16} fractional range per loop time (0.1–1 s). The corrected numerical benchmark (Appendix E, R6) integrates $\delta\tilde{\sigma}_i \simeq -(BM_{\text{pl}}^2/A^2N^2) S(r_E)\partial_i u (\dot{u}/c)$ on two visible ground–satellite links and a surface return route. The satellite is 2000 km above the angular bisector of two ground stations separated by 60 degrees. The physical solar gradient is retained, and parametric quadrature converges from 32 to 256 nodes per leg. Under the explicitly defined dimensionless normalization $BM_{\text{pl}}^2 = B_0[c/H_0]^2 u^2(1+u^2)^{-1} \exp(-u^4/2\sigma_B^4)$ with $B_0 = +1$, the signed result for the stated orientation is $H_{\text{resid}} \simeq -4.33 \times 10^{-13}$ s. The spherical-field and exact-connection ($S = 1$) controls return zero within numerical precision; setting $B_0 = 0$ or $\dot{u} = 0$ gives zero, and orientation reversal changes the sign. This is a conditional non-exact-connection benchmark, not yet an absolute prediction from the universal action. Its dimensionless B_0 must not be identified directly with the dimensionful strong-field normalization. The repaired calculation supplies a reproducible forward

test for the completed field solution without fixing a universal amplitude ceiling or excluding that solution from a null at the benchmark sensitivity.

The reduced connection keeps the assumed radial screening profile $S(r_E)$ separate from the Earth–Sun field u . This separation permits a nonzero curl because $d[S(r_E)f(u)du] = dS \wedge f(u)du$; the drift weight $W(u)$ alone is a function of the field and cannot generate circulation. The calculation therefore tests the numerical transport of a specified connection. Deriving its active gradient, environmental screening and temporal drift from one consistent scalar configuration remains the physical completion required by Rules 11, 13 and 18. Uniform drift alone need not make an otherwise non-exact screened connection exact.

Error budget (fractional per loop, targets after months):

- Clock instability after averaging: 5×10^{-19}
- Two-way calibration residual: 2×10^{-19}
- Troposphere residual: 2×10^{-19}
- Fiber path noise after stabilization: 5×10^{-20}
- Ephemeris/geodesy: 2×10^{-19}
- GR subtraction residual: 5×10^{-19}
- **Total systematic floor (rss):** $\sim 8 \times 10^{-19}$

Target: below 10^{-18} ; projected capability with advanced turbulent cancellation techniques reaches the 10^{-19} regime.

Falsification. Null at the 10^{-18} fractional target across seasons/geometry bounds the non-exact-transport kernel and normalization at the calibrated level; reaching the projected 10^{-19} capability would bound the disformal normalization at $|B_0| \lesssim 5 \times 10^{-8}$, more than four orders below the value the volume-balance reconstruction required ($|B_0| \sim 3 \times 10^{-3}$; Appendix E, R5) — an independent observational exclusion of the channel already closed analytically by its own null cone (Section 4, small- B EFT). The same calibration carries a terrestrial consistency condition: laboratory resonator and isotropy tests bound the directional cone deformation $B(\phi)(\partial\phi)^2$ at the $\sim 10^{-18}$ level, which at $|B_0| \sim 3 \times 10^{-3}$ is respected only if the near-surface shear pinning reaches $S_\Sigma \lesssim 10^{-10}$ — four orders of magnitude deeper than the solar-vicinity Cassini value. This is a consistency condition whose verification belongs to the same open single-body calculation as the Solar-System source charge (Section 7), not a derived output of the stated screening operator; and because the quoted $|B_0|$ calibration sits on the sign-excluded branch, the required pinning relaxes with whatever amplitude the admissible $B \geq 0$ realization supplies. The condition is in any case decoupled from the loop signal: the resonator bound tests $B(\phi)\Sigma^2$ at the surface, while the holonomy tests $B(\phi)\Sigma \dot{u}$ integrated along the transit.

B. Portable-clock "clock anholonomy"

Design. Two identical optical clocks transported from A to B along distinct paths (e.g., sea-level highway vs. mountain pass), durations ~ 1 –3 days, then compared at B to a stationary clock. Common-view time transfer provides epoch.

Prediction. Path-dependent discrepancy Δ_{12} at $\text{few} \times 10^{-19}$ for plausible $\alpha\dot{\phi}_0$ and $\partial_h \ln A$ under screening; null at 10^{-20} bounds $\partial_t \ln A$ and $\partial_h \ln A$ tightly. The smooth matter-frame lapse $A \cdot N$ reproducing standard gravitational redshift is subtracted within the σ_{GR} modeling, so the observable residual Δ_{12} is sourced strictly by temporal-landscape fluctuations $\delta \ln A$ beyond the smooth Newtonian potential and by the time-dependent conformal drift $\partial_t \ln A$.

Systematics. Temperature, vibration, transport-induced shifts, gravitational potential changes modeled and controlled; use transport pods with environmental control.

C. Multi-species clock network: annual modulations

Network. Global network of optical clocks (Sr, Yb, Al^+ , Hg^+ , Ca, H(1s–2s)) cross-compared over years.

Conditional extension-sector test. Phase-locked annual modulations in differential ratios ν_A/ν_B with amplitudes 10^{-19} – 10^{-17} , phases tied to orbital eccentricity. The universal conformal factor cancels identically in co-located dimensionless ratios (Section 9), so this channel tests non-universal sectoral couplings rather than the canonical action: species-amplitude ratios reflect $\alpha_A - \alpha_B$; a fit yields $\alpha(\phi)$ and dilaton coefficients d_e, d_μ, d_q .

Nulls. Compare to environmental seasonality, tidal potentials, solar activity; require phase-locked global coherence characteristic of orbital eccentric anomaly.

D. Interplanetary one-way optical time transfer

Design. Two drag-free spacecraft with 10^{-18} -class optical lattice clocks, separated by 1–5 AU. Optical comb-based one-way time transfer, with third node for calibration (Earth or a relay). Kinematic synchronization via slow-clock transport or common-view transponders.

Benchmark sensitivity window. Geometry-dependent one-way asymmetry parameter $\Xi_{AB} \equiv (t_{AB} - t_{BA})/(t_{AB} + t_{BA})$ at 10^{-15} – 10^{-14} (0.05–5 ps) for disformal tilts consistent with GW bounds. The absolute signal magnitude remains to be derived from the solved path-dependent kernel; this range is a benchmark target, not a no-refit prediction.

Systematics. Plasma delays, pointing jitter, thermal drifts, deep-space clock performance; anticipate >decade timeline.

E. Clock Network Correlation Analysis and Environmental Screening Maps

Objective. Detect spatial correlations and environmental screening signatures in atomic clock frequency residuals consistent with screened scalar field coupling $A(\phi)$ to transition frequencies.

Design.

Phase I - Distance Correlation Analysis:

- Analyze existing precision clock networks (GNSS, optical clock arrays) for distance-dependent correlations in frequency residuals
- Apply phase-coherent cross-spectral analysis between station pairs
- Bin pairs by 3D distance, fit exponential correlation model: $C(r) = A \cdot \exp(-r/\lambda_T) + C_0$
- Cross-validate across independent analysis centers to control systematics

Phase II - Environmental Screening Maps:

- Deploy identical optical clocks at sea-level, mountain, stratospheric balloon, and LEO; intercompare with two-way optical links
- Subtract GR redshift and Doppler shifts; correlate residuals with detailed geophysical models and gravimetry to isolate screening signatures

Forecast.

- Distance correlations: Exponential decay with characteristic length $\lambda_T \sim 1,000$ – $10,000$ km for viable screening parameters. The empirical terrestrial calibration $L_c \approx 4,200$ km, obtained from GNSS clock analysis (Papers 1, 2, 6), and the held-out MGEX multi-GNSS replication $\lambda = 1,862 \pm 155$ km (cluster-robust; within-fit ± 112 km; Paper 14; single-year realizations scattering across 1,050–1,935 km) represent empirical calibrations across differing constellation geometries and filter transfer functions; their containment within the decade-wide $\lambda_T \sim 1,000$ – $10,000$ km window represents a broad consistency check rather than an independently derived parameter prediction. Forward analyses that adopt $\lambda_T \approx 4,200$ km should state it as a calibration input.
- Altitude dependence: 10^{-19} – 10^{-18} frequency shifts over tens of kilometers for $\lambda_{\text{scr}} \sim 10$ km near Earth
- Multi-center cross-validation expected to show ~ 10 – 15% variation in fitted parameters (revised from the v0.4 forecast of $< 5\%$ after Paper 1)

F. Multi-messenger ensemble

Design. Stack $N \gtrsim 30$ multi-messenger events with prompt EM counterparts; marginalize astrophysical lag distributions. Seek distance-correlated trends in $t_{\text{EM}} - t_{\text{GW}}$.

Prediction. In late-time conformal subclass, no kinematics-induced trend; disformal residuals bounded to sub-100 ms over 40–200 Mpc. Nulls constrain $B(\phi_0)(\partial\phi)^2$.

11. Statistical and Open Science Principles

Pre-registration. Publish analysis plans (models, priors, nulls, thresholds) for triangle and portable-clock experiments; record any deviations.

Blinding. Blind event-time stamps and calibration offsets; employ independent teams for calibration and analysis.

Open data/code. Release raw timestamps, environmental monitors, calibration logs, and pipelines with DOIs; release CLASS/HyRec modification, atom-sensitivity database, and meta-analytic code.

Hierarchical inference. Use heavy-tailed likelihoods (Student-t) to mitigate outliers; multi-level random effects by domain; selection models for publication bias; explicit covariance modeling for shared systematics.

12. Addressing Critiques and Clarifying Claims

No EM–GW kinematic delay in conformal subclass. With $B = 0$ today, EM and GW share null cones; any observed delays are astrophysical/source or detector-time-standard effects. Because the apparent macroscopic expansion is carried natively by the dual-frame conformal unit drift of Section 8 rather than by a physical spatial stretching or disformal metric deformation, the cosmology does not drive B to large late-time values, and the shared-cone structure is preserved without fine-tuning. Earlier overstatements are corrected and aligned with GW170817 constraints.

Static ϕ gradients do not generate directional propagation asymmetry. The conformal factor cancels from the null condition (Appendix A2), so $A(\phi)$ cannot act as a photon refractive index; clock-rate and open-path redshift effects remain.

Holonomy invariant and not a synchronization artifact. The observable H_{resid} is constructed from physical proper-time measurements as the closed-loop integral of the GR-subtracted synchronization connection, $\Delta\sigma = \tilde{\sigma} - \sigma_{\text{GR}}$. Synchronization re-gaugings shift both the matter-frame connection and the corresponding GR reference connection by the same exact one-form, leaving $\Delta\sigma$ and therefore H_{resid} invariant.

Causality and hyperbolicity. The disformal matter-metric causality analysis is established in the canonical small- B EFT regime, while the noncanonical $P(X)$ scalar characteristic conditions ($v_{\parallel}^2 = 1 + 2XP_{,XX}/P_{,X} > 1$ on the selected branch) are separately certified in §2.2 and Appendix E; in this preferred-foliation khronon EFT, $v_{\parallel}^2 > 1$ establishes classical Cauchy hyperbolicity and absence of closed timelike curves on the cosmic foliation rather than claiming a Lorentz-invariant UV completion, while matter-frame causality is preserved throughout the physical branches. The small- B regime is safe.

The cosmological implementation has been tested with native hi_class MCMC fits (Paper 18) and Cobaya joint-likelihood analyses (Paper 26), demonstrating that the temporal-horizon architecture respects Planck acoustic anchors while producing late-time environmental observables. In the inhomogeneous realization the constraint equation does not require a residual Hubble-scale curvature: with ${}^{(3)}R = 2\rho_{\text{tot}}/M_{\text{Pl}}^2 + \mathcal{K}_{ij}\mathcal{K}^{ij}$ the gravitational-frame mean curvature vanishes on the constraint-satisfying landscape, and the observationally relevant curvature is the matter-frame quantity $|\Omega_k^{\text{eff}}| \sim \langle |\nabla u|^2 \rangle / H_{\text{drift}}^2$, controlled by landscape gradient contrast and reaching the observationally flat regime for the spatial contrast the redshift scatter implies (Section 8).

13. Philosophical and Conceptual Implications

Simultaneity beyond Einstein. Special relativity makes simultaneity observer-dependent; dynamic time permits globally non-integrable synchronization through its non-exact transport sector. The invariant content is a holonomy of time transport: moving clocks around closed loops in a dynamical time background returns path-dependent offsets after subtracting GR effects.

Constants clarified. The speed of light is an invariant in local tangent spaces; globally, " c " is not a number but a family of operational ratios dependent on clock histories in a time field. Variation of constants becomes a question about dimensionless ratios across environments and epochs.

Machian undertone. The rate of time responds weakly to the stress-energy of matter through αT , giving a principled, covariant flavor to the idea that the "rest of the universe" influences local rates, without violating local physics.

14. Conclusions

This paper articulates a covariant matter-metric framework realized on a preferred-foliation gravitational effective field theory in which the rate of time is a dynamical field with universal matter coupling. The architecture preserves matter-frame local Lorentz invariance and null-cone structure (in the conformal limit), conforms to multi-messenger bounds, and yields new invariant

observables—synchronization holonomy and clock anholonomy—whose GR-subtracted residuals vanish in GR and are measurable with modern clocks.

The Temporal-Shear response is realized explicitly by the nonlinear kinetic sector $P(X, \phi) = -V(\phi) + \frac{2k}{3\Lambda_X^2} X|X|^{1/2} + X|X|/\Lambda_X^4$ ($P_{,X} = k\sqrt{\xi} + 2\xi$, $k \simeq 16$ fixed by the adopted a_0), selected by the corpus's admissibility scan and confirmed by the wide-binary joint test at zero per-system free parameters — it derives the environmental inverse stiffness, the characteristic acceleration scale, the flux-conserving recovery profile, the transition-radius scaling, the flat galactic asymptote, and the distinct comparable-mass and hierarchical screening regimes, with static ellipticity and time-dependent hyperbolicity/no-ghost conditions certified on the adopted branch; remaining precision-test calculations are observable projections and finite-source boundary-value problems of this fixed kinetic realization rather than unspecified screening physics, while uniqueness within the wider $K(X)$ class, the microscopic origin and uniqueness of the admissible $X \rightarrow 0$ regulator, and the microscopic form and normalization of the disformal sector $B(\phi)$ remain open calculations. The theory is falsifiable with realistic experiments: a null closed-loop residual at the 10^{-18} fractional level, after full GR subtraction, bounds the disformal normalization and excludes the holonomy channel at the stated benchmark scale (while theory-level exclusion of the holonomy sector requires the completed $B(\phi)$ realization to fix a non-zero lower bound). The framework promises to clarify persistent cosmological tensions.

Einstein moved physics from absolute time to relative simultaneity and dynamic geometry; TEP extends this programme by governing the local calibration of proper time through a dynamical scalar field. TEP formulates this through explicit two-metric axioms and identifies a static, eternal, non-expanding gravitational geometry as its target cosmological realization: the exact and numerical model branches constructed here establish the existence of solutions in which apparent cosmological expansion and early-universe thermal history arise as temporal transport on an on-shell inhomogeneous temporal landscape, while deriving the observed redshift–distance history from a single fixed universal potential without per-branch reconstruction remains an open cosmological closure task. The framework separates the macroscopic Temporal Shear—which drives structure and dynamics—from the topological saturation that screens it where the ambient landscape is steep.

The two-metric architecture yields a proposed standard-siren discriminator, $(d_L^{\text{GW}}/d_L^{\text{EM}} = A(z) = 1/(1+z))$, arising from the distinct gravitational propagation and matter-frame measurement sectors. The source-to-detector mapping is derived at leading quadrupole order on the tensor branch — Einstein-frame sourcing mass $\mathcal{M}_e = A_e \tilde{\mathcal{M}}$, stationary-coordinate transport, matter-frame readout — returning the detector-inferred ratio $1/(1+z)$ together with the chirp-mass map $\mathcal{M}_{\text{det}} = A_o A_e \tilde{\mathcal{M}}$ — moderated to $\mathcal{M}_{\text{det}} \propto (1+z)^{3\epsilon-1}$ by BBH interior tracking; the corresponding SN Ia tracking prescription is conditionally bounded to $\epsilon < 0.150$ (3σ , $\Delta\chi^2 = 805.8$ at $\epsilon = 1$) by Pantheon+ on the fixed- $z_T = 5$ M1 branch, with the host-assembly transfer giving $\epsilon_{\text{eff}} \simeq 0.004$ for deep-well SN Ia hosts versus 0.24–0.52 for field-spiral/dwarf BBH hosts and the GWTC empirical optimum at $\hat{\epsilon} = 0$ (Section 8) — whose inverse direction relative to the FLRW convention is itself a population-level discriminator; scalar-mode admixture and higher-order back-reaction remain within the gravitational-wave programme. It enforces sign-definite deviations from GR ($\gamma_{\text{PPN}} < 1$), yields measurable invariant observables like residual synchronization holonomy where the drift rate's gradient is misaligned with the field gradient (the disformal-curvature condition $d(\delta\bar{\sigma}) \propto d(\dot{\phi}/N^2) \wedge d\phi$), and provides sharp multi-messenger discriminators. If residual holonomies at the targeted scale and the predicted cosmic distances are observed, physics will enter a new epoch in which dynamic time joins dynamic geometry as a foundation. If not, uniquely strong bounds will have been set and the operational bedrock of c and simultaneity clarified to unprecedented precision.

14.1 Recovering GR is Not Regressing to GR

Recovering standard General Relativity in the Solar System is not a regression—it is the baseline requirement to avoid being immediately falsified by a century of precision experimental data. The effective screened limit recovers GR to the required observational accuracy where GR is experimentally established (local, screened systems), while permitting distinct phenomenology on unscreened astrophysical and cosmological scales. The framework remains radically non-GR:

- **GR has one metric; TEP has two.** In GR, geometry is dictated solely by the Einstein tensor of $g_{\mu\nu}$. In TEP, all matter, light, and clocks move along geodesics of a distinct, dynamical matter metric $\tilde{g}_{\mu\nu}$.
- **Standard GR-based cosmology requires dark matter; in TEP the dynamical phenomenology arises from Temporal Shear, and in the unstretched-space temporal foliation the corresponding lensing phenomenology arises from intermediate temporal depth.** Galactic rotation curves motivate the dark-matter comparison, while wide binaries test the local weak-field force law without requiring a dark halo around each pair. In TEP, active Temporal Shear bends matter geodesics. The selected two-branch kinetic sector supplies the bounded local enhancement of Section 7 on its quadratic branch ($\xi \gg \xi_* \simeq 64$, the regime of every Solar-System benchmark) and the flat outer rotation curves with baryonic Tully–Fisher scaling on its low-gradient branch, tested against SPARC in Paper 6, Steps 10–13. The two branches are terms of the single action $P_{,X} = k\sqrt{\xi} + 2\xi$: the same sector passes the local, binary and galactic tests jointly — the corrected wide-binary joint test excludes the unit-term baseline and the exponential-interpolation rival at $\sim 30\sigma$ on amplitude while passing the selected sector at $\sim 0.4\text{--}1.7\sigma$, and under the action-derived additive force law $g_{\text{obs}} = g_N + a_\phi$ ($P_{,X} = \epsilon_{\text{reg}} + k\sqrt{\xi} + 2\xi$, $\epsilon_{\text{reg}} = 10^{-3}$, $k_* = 16.03$ calibrated to a_0) the SPARC fit returns RMS 0.2185 dex at $\Upsilon_d = 0.5$ and 0.2004 dex at $\Upsilon_d = 0.35$ (matching the empirical MOND reference 0.1989 dex and outperforming the 0.2812 dex unit-term baseline by > 60 mdex; phenomenological quadrature comparator $\sqrt{g_N^2 + a_\phi^2}$ gives 0.1974 dex at $\Upsilon_d = 0.5$ with $k_{\text{fit}} = 15.78$ and outer-edge BTFR median $v_{\text{obs}}/v_{\text{pred}} = 1.0109$). In the optical sector, isotropic conformal rescaling $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu}$

stretches spatial rulers by the same factor $A^2(\phi)$ as clocks, causing $A^2(\phi(x))$ to cancel out of $d\tilde{s}^2 = 0$ at every intermediate point along a photon path and leaving only the Planck-suppressed scalar stress tensor ($\kappa_\phi \simeq 6.5 \times 10^{-6}$ on the selected sector; Paper 19, Step 64). Under the canonical unified matter metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ ($U_\mu \equiv -\nabla_\mu \tilde{\phi} / \sqrt{2\tilde{X}}$) — where the $(3+1)$ ADM lapse rescales as $N_{\text{TEP}}(\mathbf{x}) = A_{\text{loc}}(u_{\text{grav}}(\mathbf{x}))N_{\text{GR}}(\mathbf{x})$ while at a fixed cosmic epoch ($A_{\text{sp}}(t_0) = 1$) the spatial 3-metric $\tilde{\gamma}_{ij} = \gamma_{ij} = (1 - 2\Phi_N/c^2)\delta_{ij}$ remains unstretched — intermediate clock rates between source and observer do not cancel: every point x along the ray contributes its local temporal depth $-\beta_A u_{\text{grav}}(x)$ directly to the refractive index $n(x) \simeq 1 - 2\Phi_N(x)/c^2 - \beta_A u_{\text{grav}}(x)$. Because both transverse-traceless tensor perturbations h_{ij}^{TT} of γ_{ij} and electromagnetic waves obey the identical principal wave operator $\square_{\text{TEP}} = -(N_{\text{TEP}}c)^{-2}\partial_t^2 + A_{\text{sp}}^{-2}(t, \mathbf{x})\gamma^{kl}\partial_k\partial_l$ from the spatially covariant ADM/DHOST action S_{grav} on static space γ_{ij} (rather than splitting into a photon-only disformal cone or an unshared tensor operator, which GW170817 would exclude by $\sim 10^7$ s across haloes or $\sim 6.9 \times 10^5$ yr across the IGM; Boran et al. 2018; Step 80), $c_{\text{GW}}(t, \mathbf{x}) = c_\gamma(t, \mathbf{x}) = c N_{\text{TEP}}(\mathbf{x})/A_{\text{sp}}(t, \mathbf{x})$ and $\Delta t_{\gamma-\text{GW}} = 0$ hold identically across haloes, voids, and cosmic epochs alike, while Solar-System Shapiro bounds remain satisfied via the quadratic-branch screening $y \sim (r/r_*)^{4/3} \ll 10^{-5}$. Sourced by baryons alone ($f_b = 0.16$, zero CDM) on the zero-free-parameter selected sector $P_{,X} = k\sqrt{\xi} + 2\xi$, this unstretched-space temporal refraction reproduces the non-baryonic Fermat delay and arrival order of SN Refsdal (+330.9 d sheet solve, +221.6 to +443.2 d 3-D deprojected NFW ray solve; Paper 19, Step 64), the galaxy-peak convergence and offset morphology of the Bullet Cluster ($\kappa_{\text{tot}} = 0.307\text{--}0.372$ at the bullet galaxies with no negative moat; Paper 4, Step 02), and the cosmic-web amplification required by the Planck CMB lensing spectrum ($9.4 \times -129 \times$ boost across $g_b/g_t \sim 8 \times 10^{-4}\text{--}5 \times 10^{-3}$; Paper 18, Step 21).

- **Standard GR-based cosmology models redshift as expanding space from a Big Bang; TEP rejects both.** The standard cosmological interpretation asserts that space itself physically stretches. TEP holds that the gravitational spatial geometry γ_{ij} is eternal and static (carrying zero Hubble friction in the tensor sector, $\Xi(z) = 1/(1+z)$), while cosmological ruler evolution and redshift reside in the chronometric recalibration of the matter metric (A_{sp}).
- **GR predicts the reference synchronization holonomy; TEP permits an additional residual.** GR itself produces closed-loop transport effects such as the Sagnac term; the residual remaining after the complete GR contribution is subtracted vanishes. TEP permits a nonzero closed-loop synchronization residual sourced by non-exact temporal transport ($H_{\text{resid}} \neq 0$).
- **Standard GR-based clock models do not predict TEP's residual spatial covariance.** After accounting for known gravitational, environmental, and measurement correlations, TEP predicts a distance-structured residual across continental baselines ($C_A(r) \propto \exp(-r/\lambda_T)$ with $\lambda_T \sim 1,000\text{--}10,000$ km). Standard geodetic pipelines apply common-mode signal removal that demonstrably attenuates injected clock offsets (Paper 1 reports $\approx 96\%$ attenuation in CODE R5 injection tests), yet the measured correlation survives in the residuals — consistent with a physical signal that reduction attenuates rather than eliminates.

14.2 Master Falsification Ledger and Deciding Observables

The program maintains an explicit master ledger of its primary empirical claims, open closures, and deciding observables. Each item is paired with a quantitative falsification criterion and a definitive observational or computational channel; statuses cite the registered pipeline outputs on which they rest.

Load-bearing item	Current status in corpus	Deciding observable / test	Falsification criterion
Static-frame stability (§8; Papers 0, 27)	Positive restricted finite-cell spectra and independent discrete bounds (Steps 79/82); a positive canonical evolving-CMC initial lapse and a khronon stress-shift lapse diagnostic (Step 21); complete matter-coupling second variation $\mathcal{V}_{\text{eff}}'' = V_{\text{rec}}'' + \rho_*(x)e^{-u}$ flipping the unprojected canonical reconstructed spectrum from -0.4389 to $\lambda_0 = +0.4123\text{--}0.4127 > 0$ (completed_canonical_reconstructed_coupled_audit); and two quartic constrained-operator benchmarks in Step 79 — one with a prescribed scalar profile and re-solved Hamiltonian geometry, and a companion jointly on-shell solve where both the nonlinear two-branch scalar Euler–Lagrange equation and the Lichnerowicz Hamiltonian constraint converge to $< 3.1 \times 10^{-12}$ ($N = 16, 24$, unprojected coupled $\lambda_0 = +0.5624\text{--}0.5633 > 0$, all-twist bound $+0.4662\text{--}0.4668 > 0$ under volume-constrained metric response $q_{\text{vol}}^T \delta\psi = 0$). These results establish their stated initial-slice and finite-grid operator properties; they do not establish full-action continuum time evolution.	Higher-resolution ($N \geq 64$) multi-scale continuum coupled evolution and radiative damping rates across cosmic lookback time.	Appearance of a physical volume-gauge-preserving inhomogeneous mode with negative eigenvalue in the coupled Einstein–scalar operator
Optical-sector lensing (Papers 4, 18, 19)	Unified matter metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ and spatially covariant ADM/DHOST gravitational action S_{grav} derived and symbolic-verified (Step 80): preserves static Poisson/scalar equations ($\delta S_{\text{grav}}/\delta u_{\text{grav}} = 0$, $\delta S_{\text{grav}}/\delta A_{\text{sp}} = 0$ at $K_{ij} \rightarrow 0$), enforces $c_{\text{GW}}(t, \mathbf{x}) = c_\gamma(t, \mathbf{x}) = c N_{\text{TEP}}(\mathbf{x})/A_{\text{sp}}(t, \mathbf{x})$ ($\Delta t_{\gamma-\text{GW}} = 0.0$ s for GW170817) and constant WKB tensor measure $\sqrt{A_{\text{sp}}^{+1} \cdot A_{\text{sp}}^{-1}} = 1$ on static	Stellar-kinematics mass-sheet breaking across strong-lens ensembles (including SN 2025wny); native	Systematic absence of the predicted time-delay scale shift across kinematics-calibrated (mass-sheet-broken) long-baseline strong-lens

Load-bearing item	Current status in corpus	Deciding observable / test	Falsification criterion
	space ($\Xi(z) = 1/(1+z)$), gives PPN slip $\gamma_{\text{PPN}} - 1 = -2\beta_A^2 S_\Sigma / (1 + 2\beta_A^2 S_\Sigma)$ ($ \gamma_{\text{PPN}} - 1 \simeq 4.32 \times 10^{-8}$ at $1.6 R_\odot$), and on the selected two-branch sector reproduces Refsdal Fermat delay (+330.9 d sheet, +221.6–443.2 d 3-D ray; Step 64), Bullet galaxy-peak convergence ($\kappa_{\text{tot}} = 0.307\text{--}0.372$, no moat; Paper 4 Step 02), and Planck 2018 CMB lensing spectrum at $\omega_{\text{cdm}} = 0$ ($\chi^2 = 15.40$ fixed-Silk, 13.40 4-param vs 12.30 CDM; Paper 18 Step 21)	Boltzmann perturbation transfer of the unstretched-space temporal refractive potential	ensembles; failure of the unstretched-space temporal convergence profile in cluster or CMB lensing
LLR synodic residual (Paper 17)	Precision-weighted residual detection $\eta_{\text{resid}} = -(3.91 \pm 0.56) \times 10^{-4}$ (-5.08 ± 0.73 mm, 6.9σ) in INPOP19a post-fit residuals (cross-ephemeris support in DE430); on the single two-branch solar solution that passes Cassini ($y_{\text{tb}}(1.6 R_\odot) = 2.16 \times 10^{-8}$, $y_{\text{tb}}(1 \text{ AU}) = 1.47 \times 10^{-5}$), the direct solar scalar optical excursion is screened to $\delta u_\odot^{\text{tb}} = 7.4 \times 10^{-16}$ ($\eta_{\text{tb}} = -1.1 \times 10^{-8}$), consistent with direct-fit LLR bounds alongside Cassini (and axisymmetric coupled syzygy PDE solves confirm zero $P_{,X} < 1$ bridge volume at both Full and New Moon; Step 086). Because TEP's unified metric at a fixed cosmic epoch inside the screened Solar System ($A_{\text{sp}}(t_0) = 1$) has spatial 3-metric $\tilde{\gamma}_{ij} = \gamma_{ij} = (1 - 2\Phi_N/c^2)\delta_{ij}$ identical to GR's, the Newtonian solar tidal differential $\Delta\Phi_{N,\odot}/c^2 = 2.54 \times 10^{-11} \cos D$ (unscreened reference ceiling -4.85 mm, $\eta_{\text{ceiling}} = -3.73 \times 10^{-4}$; Step 083) cancels in BCRS $\rightarrow$ GCRS identically to GR, and η_{resid} stands as an empirical post-fit residual-channel detection awaiting a source-level integrator refit	Full numerical orbit-integrator refit (INPOP/DE430-class) with η_{resid} left free in the dynamical equations	Complete absorption of the synodic $\cos D$ amplitude into standard ephemeris parameters ($\eta_{\text{resid}} \rightarrow 0$) during integrator-level refit
BBN & VMO recycling (Paper 29)	Asymptotic chemical equilibrium yields $Y_{\text{eq}} \approx 0.247$; Strömgren ionization budget computed (margin ≈ 0.97); deuterium extended channels ledger registered	Pop-III stellar archaeology; nucleosynthetic yield matching from VMO partial-burning ejecta (f_{VMO})	Direct stellar-archaeological exclusion of metal-free VMO enrichment channels; failure to sustain D/H $\approx 2 \times 10^{-5}$ under bounded astration
J0437 phase closure (Paper 16)	Phase-domain detection $\psi = 1.12$ rad ($p = 1.3 \times 10^{-44}$); canonical disformal connection supplies 1.3% (5.0% on p_{95} leg) at $B_0 = +1$ unit benchmark and reaches 100.5% (median leg, $B_0^{\text{req}} = 77.3$; $B_0^{\text{req}} = 20.1$ on p_{95} leg) at the GW170817 galactic-profile envelope $B_0 \lesssim 77.7$ (Step 057); within-source sub-band delay ratio consistent with achromatic transport (Step 061)	Multi-pulsar phase closure (PSR J1603-7202, MeerKAT samples); secondary-spectrum arc curvature & DM regression	Scaling of the delay with ν^{-2} (plasma dispersion) across octave bands; absence of phase-closure concentration in independent high-dispersion pulsars
Cosmic shear S_8 (Paper 18)	CMB joint MCMC gives $S_8 = 0.868 \pm 0.025$; provenance audit (Step 23) shows it is prior-boundary dominated (A_{planck}/n_s saturate ceilings; σ_8 tracks A_{planck} at $r = +0.46$). Perturbation-closure audit (Oct 2026, corrected $\delta\phi$ solver): the canonical-EF map $\alpha_K = -5\alpha_A^2$ is linearly unstable (tachyonic scalarization; $D > 0$ insufficient); unscreened stable branch excluded ($\sigma_8 \simeq 1.6$); screened kineticity branch $Z_E \gtrsim 700$ recovers ΛCDM ($\sigma_8 = 0.824$ vs 0.823), with $\sigma_8 \simeq 0.76$ — the weak-lensing value — at $Z_E \sim 6 \times 10^3$	Stage-IV weak lensing (Euclid, Rubin LSST, Roman) tomographic cosmic-shear power spectra constraining the scalar kinetic coefficient Z_E ; the low- ℓ ISW excess that accompanies the growth-suppressing branch ($w_c \sim 6 \times 10^3$)	Exclusion of the screened branch — measured growth incompatible with the $\sigma_8(Z_E)$ response curve at every $Z_E \gtrsim 700$, or a low- ℓ ISW level incompatible with the signature the growth-suppressing branch predicts
GNSS clock correlations (Papers 1, 2, 3)	Spatial covariance $\lambda_T \approx 3,210 \pm 389$ km; orbital-velocity correlation $r = -0.888$; velocity vs calendar model comparison registered (Step 2.10: generic annual sinusoid preferred globally, orbital-waveform discrimination underpowered at 10-day resolution)	Independent-chain time transfer: raw TWSTFT inter-laboratory clock links (BIPM time-transfer archive, PTB-pivot network) and optical-fibre time-	Complete disappearance of the $\sim 3,000\text{--}4,000$ km correlation structure in non-GNSS (TWSTFT/fibre) clock networks — sharpest form: a GNSS-versus-

Load-bearing item	Current status in corpus	Deciding observable / test	Falsification criterion
		transfer links — BIPM Circular T itself is dominated by GPS PPP links and does not by itself constitute a non-GNSS channel; synthetic GNSS signal injection through the estimation chains	TWSTFT difference on identical laboratory clock pairs must retain the structure in both arms if the field is environmental — or identification as an IGS datum-processing artifact via product-level signal injection; the decisive test requires satellite-scale non-GNSS data (optical inter-satellite links, raw TWSTFT sessions, or a GNSS product-level injection)
Standard sirens $\Xi(z)$ (Paper 22)	Physical high-mass cutoff fitting breaks scale-free degeneracy ($\beta \simeq 154 M_\odot$ TEP vs $33 M_\odot$ GR); canonical pinned TEP out-performs stationary GR by $\Delta \ln L = +2.32$ out of sample on 50 high- z events ($\ln L = -188.68$ vs -191.00 , conditional likelihood ratio ≈ 10.2), with global profile optima at canonical baselines ($\hat{\epsilon} = 0, \hat{k} = 0$); progenitor-dependent host transfer derived ($\epsilon_{\text{eff}} \simeq 0.004$ SNe Ia vs $0.24\text{--}0.52$ BBHs)	LVK O4/O5 bright standard sirens with spectroscopic host identification; detector-frame chirp-mass population trend	Spectroscopic bright sirens at $z \gtrsim 0.3$ confirming standard $d_L^{\text{GW}} = d_L^{\text{EM}}$; detection of $(1+z)\mathcal{M}$ chirp-mass trend without tracking

14.3 Evidential Hierarchy and Degree-of-Freedom Accounting Across the Corpus

Across the specialized studies of the TEP corpus, empirical channels fall into four distinct degree-of-freedom classes. Separating these classes prevents anchor calibration from being conflated with out-of-sample confirmation and defines which channels carry independent statistical weight:

Evidential class	Free TEP parameters (k_{fit})	Representative channels & quantitative status	Evidential role
I. Zero-parameter & model-independent tests	$k_{\text{fit}} = 0$ (fixed by $\beta_A = -1, a_0$, or native coordinates)	KBC-void / MOND expansion falsification on native Pantheon+ coordinates ($\Delta\chi^2 > 100, 8.4\sigma/9.7\sigma$, competitor exclusion; Paper 31); wide-binary joint force-law profile ($P_{,X} = k\sqrt{\xi} + 2\xi, k_* = 16.03$ fixed by a_0 , passing at $0.4\text{--}1.7\sigma$ while excluding unit-term and exponential rivals at $\sim 30\sigma$; Paper 13); SPARC RAR additive force law at fixed $k_* = 16.03$ (RMS = $0.2004\text{--}0.2185$ dex; Paper 6); unstretched-space baryon-only Fermat delay and Bullet Cluster convergence (Papers 4, 19); GWTC-3 BBH high- z chirp-mass cutoff ($\Delta \ln L = +2.32$ out of sample at $\hat{\epsilon} = 0, \hat{k} = 0$; Paper 22).	Primary load-bearing empirical discriminators; no per-dataset tuning.
II. Terrestrial-anchor propagated tests	$\rho_T \approx 20 \text{ g cm}^{-3}$ fixed on Earth ($L_e \approx 4,200 \text{ km}$); $k_{\text{fit}} \leq 1$ channel transfer norm	Universal $R_T \propto M^{1/3}$ saturation scaling from GNSS ($R_T(M_\oplus) \approx 4,150 \text{ km}$; Papers 1–3, 14) to Earth flyby perigee asymptote ($R_{\text{sol}} = 4,146 \text{ km}$, $\Delta\text{BIC} \gtrsim 1.66 \times 10^4$ vs null at $k_{\text{fit}} = 1$; Paper 15), Cepheid envelope density threshold ($\rho_T/\langle\rho\rangle$ predicting κ_{P2} to 0.5% of the SH0ES central estimate, $(1.191 \pm 0.480) \times 10^6 \text{ mag}$; Paper 11), globular-cluster MSP spin-down suppression ($\Gamma_{\text{obs}} = 0.393 \pm 0.079$ vs literature-consensus Newtonian $0.748 \pm 0.039 [4.1\sigma]$ and structurally rescaled 20-cluster $0.860 \pm 0.058 [4.8\sigma]$, plus 8.6σ 20-cluster ensemble-propagated and 4.1σ fully-correlated ceiling excess across the 14 unique CMC realizations; Paper 10), and high- z JWST age-excess scaling ($r = 0.88, 25.1\sigma$; Paper 12).	Cross-regime structural compression across 40 orders of magnitude in mass; tests scale invariance of ρ_T and $S_{\Sigma}(\mathcal{E})$.
III. Cosmological Λ	$k_{\text{fit}} = 1\text{--}2$ transport parameters in	Pantheon+ + DESI DR2 BAO + Planck θ_* joint background fit ($\Delta\chi^2 = -8.1$ vs ΛCDM ; emergent DESI-quadrant thawing	Separates reference-Boltzmann active-

Evidential class	Free TEP parameters (k_{fit})	Representative channels & quantitative status	Evidential role
CDM-parity closures	background/reference-Boltzmann runs; $k_{\text{fit}} = 0$ extra dark-sector parameters in Step-21 CDM-free closure	projection (w_0, w_a) $\approx (-0.83, -0.44)$ on that single history; Papers 26, 27); Paper 18 (a) reference Boltzmann validation with active scalar perturbations ($Z_E \gtrsim 7 \times 10^2$) and reference CDM component retained ($\Delta\chi^2 = -0.11$, $\sigma_8 = 0.824$; §§3–4) and (b) separate Step-21 CDM-free ($\omega_{\text{cdm}} = 0$) preferred-foliation construction with baryon clock-slope acoustic driving ($\omega_\phi = \omega_b y_s / \sqrt{2} = 0.1179\text{--}0.1182$) and unstretched-space temporal-depth CMB lensing ($\chi^2 = 13.40$ on Planck lensing; $\Delta\chi^2 = -0.06$, $\Delta\text{AIC} = -2.06$ on full Planck TTTEEE + low- ℓ + lensing + BAO + Pantheon+); D/H Lyman-series absorber non-uniqueness ($T = 161.03$, $p \leq 0.001$ across 3 sightlines; Paper 29).	scalar stability validation (retaining comparison CDM) from the preferred-foliation CDM-free ($\omega_{\text{cdm}} = 0$) acoustic and lensing construction and no- Λ background closure.
IV. Prospective divergent discriminators	$k_{\text{fit}} = 0$ (pre-registered sign and scale)	Continental optical-fibre clock links (PTB–SYRTE 1,415 km link, predicted 14–19% differential plateau modulation; Paper 1 §4.10); raw TWSTFT vs GNSS common-clock differences; closed-loop non-exact synchronization holonomy $H_{\text{resid}} \neq 0$ at 10^{-18} (Paper 9); spectroscopic bright standard sirens at $z \gtrsim 0.3$ (Paper 22); isolated field-galaxy strong lenses ($\gamma_{\text{SMP}} \simeq 0.81$ vs group-screened $\simeq 0.98$; Step 80).	Out-of-sample experimental and observational channels where TEP and standard GR+ Λ CDM make mutually exclusive predictions.

Multiplicity and look-elsewhere discipline. Across a 30-paper corpus, individual 2σ – 3σ auxiliary correlations would be expected by chance if treated in isolation. Accordingly, the framework's inference rests on (i) family-wise and false-discovery-rate corrected batteries within each flagship pipeline (e.g., 178/388 tests surviving FWER at $\alpha = 0.05$ across 19 validation families in Paper 1; event-block stratified permutation nulls in Paper 26), and (ii) high-significance ($> 4\sigma$ – 25σ) and zero-parameter out-of-sample channels (Class I above), while lower-significance auxiliary channels are recorded as consistency checks rather than standalone detections.

Appendix A: Proofs and Key Derivations

A1. Conformal null-cone invariance

Let $\tilde{g}_{\mu\nu} = A(\phi)^2 g_{\mu\nu}$ with $A > 0$. A vector k^μ null with respect to $g_{\mu\nu}$, $g_{\mu\nu} k^\mu k^\nu = 0$, satisfies $\tilde{g}_{\mu\nu} k^\mu k^\nu = A^2 g_{\mu\nu} k^\mu k^\nu = 0$. Maxwell's action $S = -(1/4) \int \sqrt{-g} F_{\mu\nu} F^{\mu\nu}$ is conformally invariant in 4D: under $\tilde{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}$, $\sqrt{-\tilde{g}} F_{\mu\nu} F^{\mu\nu} = \sqrt{-g} F_{\mu\nu} F^{\mu\nu}$. Hence photon geodesics are conformally invariant; null cones coincide.

A2. Exact direct conformal propagation null

Consider the purely conformal subclass $\tilde{g}_{\mu\nu} = A^2(\phi) g_{\mu\nu}$, $B = 0$. A photon trajectory satisfies

$$\tilde{g}_{\mu\nu} k^\mu k^\nu = A^2(\phi) g_{\mu\nu} k^\mu k^\nu = 0. \quad (94)$$

Because $A(\phi) > 0$, this is equivalent to $g_{\mu\nu} k^\mu k^\nu = 0$. Thus the conformal factor does not alter the local null cone or act as a direction-dependent refractive index. In a static conformal background, forward and backward propagation along the same geometrical path therefore acquire no conformal propagation-time antisymmetry:

$$\Delta t_{\text{prop}}^{(A)} \equiv t_{\rightarrow} - t_{\leftarrow} = 0. \quad (95)$$

The conformal sector nevertheless remains observable through matter-clock rates and open-path comparisons. For stationary clocks, $d\tilde{\tau} = A(\phi) d\tau_g$, so clocks situated in different field environments can acquire different proper-time histories. The corresponding infinitesimal conformal transport is $\omega^{(A)} = d \ln A$, which is exact. Hence, in a smooth simply connected region,

$$\oint_C d \ln A = 0. \quad (96)$$

A static, purely conformal field can therefore produce clock-rate differences and open-path redshift effects, but cannot by itself generate a direction-odd same-path propagation residual or a non-zero closed-loop synchronization holonomy. Such a residual requires the disformal sector $B \neq 0$, explicit time dependence combined with motion through the field, or some other non-exact/topological transport structure.

Photon theorem (general $A(x, t)$). The result does not rely on A being static, and the stronger observable statement — that the conformal contribution to a measured timing or frequency observable is endpoint-only — is a theorem of the measurement chain, not merely an inference from null-cone invariance. Two facts must be distinguished. First, at the trajectory level: for arbitrary $A(x, t)$ the unparametrized null curves of $\tilde{g} = A^2 g$ and g coincide exactly, so no conformal factor produces additional photon deflection, altered image positions, or a propagated conformal contribution to inter-image coordinate delay. Second, at the observable level the experiment measures a chain — source clock $\rightarrow$ electromagnetic phase $\rightarrow$ receiver clock — that lives entirely in $\tilde{g}$. That chain still telescopes, for two reasons. The eikonal covector $k_\mu = \nabla_\mu S$ is an affinely parametrized null geodesic covector of *both* metrics: contracting the conformal connection difference gives $k^\nu k_\rho C^\rho_{\nu\mu} = k_\mu(k \cdot \partial \ln A) - k_\mu(k \cdot \partial \ln A) = 0$, so k_μ 's transport along the path is governed by g alone, whatever $A(x, t)$ does. And the matter-frame observer on a given worldline carries $\tilde{u}^\mu = u^\mu/A$, so the measured frequency is $\tilde{\omega} = -k_\mu \tilde{u}^\mu = \omega_g/A$ evaluated locally at the point of measurement. The observed frequency ratio therefore factorizes,

$$\frac{\tilde{\omega}_{\text{obs}}}{\tilde{\omega}_{\text{emit}}} = \left(\frac{\omega_g^{\text{obs}}}{\omega_g^{\text{emit}}} \right) \cdot \frac{A_{\text{emit}}}{A_{\text{obs}}}, \quad (97)$$

where the first factor is the gravitational-metric redshift accumulated along the path and the second is endpoint-only for *any* $A(x, t)$ — intermediate evolution of A along the trajectory telescopes out identically, because the only place A enters the measurement is the normalization of the endpoint clocks. The same bookkeeping applies to arrival times: the null curves coincide as spacetime trajectories, so image i arrives at coordinate time fixed by g 's Fermat surface, and the observer's proper-time delay is $\Delta \tilde{\tau}_{\text{obs}} = A_{\text{obs}} \Delta t_{\text{obs}}$ — a single endpoint factor common to all images. Applied to the four combinations of static/evolving source and static/evolving A , the isotropic conformal sector contributes only through endpoint clock factors: emission-epoch differences at the source (the temporal-composite channel, which requires intrinsic source time-structure and vanishes for static sources), the observer-clock readout rate, and the endpoint ratio. Within the purely isotropic conformal subclass $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu}$, a genuinely path-dependent photon residual — integrated drift of $\tilde{\omega}$ along the ray, extra delay, extra deflection — cannot originate in $A(\phi)$ at any order and would instead require scalar stress-energy backreaction on $g_{\mu\nu}$ or a spatial disformal term $B(\phi)\nabla_\mu\phi\nabla_\nu\phi$ (or derivative matter couplings outside the minimal action). In the canonical resolved preferred-foliation metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ (§2.2, Step 80), by contrast, the longitudinal disformal weight $B_\parallel \equiv (A_{\text{sp}}^2 - A_{\text{loc}}^2)/(2\bar{X})$ is non-vanishing whenever $A_{\text{loc}}/A_{\text{sp}} \neq 1$: at a fixed cosmic epoch ($A_{\text{sp}} = 1$) on unstretched spatial 3-geometry γ_{ij} , spatially varying local temporal lapse $A_{\text{loc}}(u_{\text{grav}}(\mathbf{x}))$ generates reciprocity-even optical refraction $n(\mathbf{x}) \simeq 1 - 2\Phi_N(\mathbf{x})/c^2 - \beta_A u_{\text{grav}}(\mathbf{x})$ and Fermat time delays without requiring a non-zero transverse disformal coefficient $B(\phi)$ (Papers 4, 18, 19). Photon–graviton propagation coincidence ($c_{\text{GW}} = c_\gamma$, $\Delta t_{\gamma\text{--GW}} = 0$) in this resolved preferred-foliation sector follows from the shared principal wave operator $\square_{\text{TEP}} = -(N_{\text{TEP}}c)^{-2}\partial_t^2 + A_{\text{sp}}^{-2}\gamma^{kl}\partial_k\partial_l$ derived in §2.2 rather than from isotropic conformal invariance alone, while direction-odd same-path propagation asymmetry and closed-loop synchronization holonomy continue to require non-exact or transverse disformal transport ($B(\phi) \neq 0$ or time-dependent landscape drift).

A3. Synchronization holonomy invariance and projected disformal connection

This appendix derives the leading-order disformal contribution to the synchronization connection used in Sections 6 and 7 and shows why the GR-subtracted closed-loop residual is invariant under synchronization re-gauging.

A3.1 Synchronization connection and re-gauging

Consider a local threading decomposition of the matter-frame metric relative to a physical clock-network congruence:

$$d\tilde{s}^2 = \tilde{g}_{00}(dt + \tilde{\sigma}_i dx^i)^2 + \tilde{h}_{ij}dx^i dx^j. \quad (98)$$

Equivalently, up to the sign convention used for $\tilde{\sigma}_i$,

$$\tilde{\sigma}_i = \frac{\tilde{g}_{0i}}{\tilde{g}_{00}}. \quad (99)$$

If the opposite sign convention is adopted, all shifts below acquire the opposite sign, but the closed-loop result is unchanged.

A synchronization re-gauging of the same physical clock network assigns a different simultaneity offset to the same clock worldlines:

$$t' = t + \chi(x^i), \quad (100)$$

where χ is a single-valued spatial clock-offset function on the network at the epoch of the loop measurement. Then

$$dt = dt' - \partial_i \chi dx^i. \quad (101)$$

Substituting into the metric gives

$$dt + \tilde{\sigma}_i dx^i = dt' + (\tilde{\sigma}_i - \partial_i \chi) dx^i. \quad (102)$$

Therefore

$$\tilde{\sigma}_i \longrightarrow \tilde{\sigma}'_i = \tilde{\sigma}_i - \partial_i \chi. \quad (103)$$

In one-form notation,

$$\tilde{\sigma} \longrightarrow \tilde{\sigma} - d\chi. \quad (104)$$

With the opposite sign convention for $\tilde{\sigma}$, the sign reverses. In either convention, the change is exact.

The same simultaneity re-labelling acts on the threading combination g_{0i}/g_{00} of any metric in the same way. The GR reference connection σ_{GR} is the corresponding threading connection computed from the GR reference metric on the same physical clock-network congruence, with the same loop, same coordinate convention, and the standard Sagnac, Lense–Thirring, Shapiro, gravitational-redshift, station-motion, clock-scale, and reference-frame corrections included. Therefore the same re-labelling gives

$$\sigma_{\text{GR}} \longrightarrow \sigma_{\text{GR}} - d\chi. \quad (105)$$

The GR-subtracted residual connection

$$\Delta\sigma \equiv \tilde{\sigma} - \sigma_{\text{GR}} \quad (106)$$

therefore transforms as

$$\Delta\sigma \longrightarrow (\tilde{\sigma} - d\chi) - (\sigma_{\text{GR}} - d\chi) = \Delta\sigma. \quad (107)$$

Thus the closed-loop observable

$$H_{\text{resid}}(C) = \oint_C \Delta\sigma \quad (108)$$

is invariant under synchronization re-gauging.

Equivalently, if one works with a representative in which the residual connection itself shifts by an exact form,

$$\Delta\sigma \rightarrow \Delta\sigma + d\chi_{\text{res}}, \quad (109)$$

then the loop integral is still invariant because

$$\oint_C d\chi_{\text{res}} = 0 \quad (110)$$

for single-valued χ_{res} . The observable is the loop class of the residual connection modulo exact one-forms, not a raw one-way synchronization convention.

This proof is local in time. The loop C is evaluated on the spatial network at a specified epoch. Time dependence of ϕ , $B(\phi)$, or the matter metric may change the value of $\Delta\sigma$ from one epoch to another, but it does not change the synchronization-gauge argument at a fixed epoch. The gauge freedom relevant to the closed-loop observable is the spatial simultaneity re-labelling $\chi(x^i)$ of the specified physical clock network.

For experimental campaigns extending over months, the integrated data does not evaluate a single 4D spacetime loop, but rather generates a continuous time-series of instantaneous 3D spatial loop integrations, $H_{\text{resid}}(C, t)$. At any given temporal slice t , the spatial simultaneity re-labeling remains strictly exact ($\oint_C d\chi(t, x^i) = 0$). Slow temporal variations in $\phi(t)$, or shifts in the Earth's environmental screening state $\mathcal{E}$ along its orbit, merely manifest as predictable, time-dependent modulations (e.g., annual or diurnal phases) of a continuously gauge-invariant spatial holonomy.

A3.2 Projected disformal contribution

The matter metric is

$$\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu} + B(\phi)\nabla_\mu\phi\nabla_\nu\phi. \quad (111)$$

Let u^μ be the four-velocity of the physical clock network defining the synchronization protocol, with

$$u^\mu u_\mu = -1 \quad (112)$$

in the $(-+++)$ signature. The spatial projector into the local rest space of this congruence is

$$P_\mu{}^\nu = \delta_\mu{}^\nu + u_\mu u^\nu. \quad (113)$$

The scalar gradient decomposes as

$$\nabla_\mu\phi = D_\mu\phi - (u \cdot \nabla\phi)u_\mu, \quad (114)$$

where

$$D_\mu\phi = P_\mu{}^\nu\nabla_\nu\phi \quad (115)$$

is the spatial gradient measured by the clock network.

Corpus signature convention. The canonical corpus convention, used throughout this paper and Papers 1–23 and 26–37, is $(-+++)$: timelike vectors obey $u^\mu u_\mu = -1$, the matter-metric lapse satisfies $N^2 = -\tilde{g}_{00}$, timelike scalar gradients have $\Sigma^2 = (\nabla\phi)^2 < 0$, and the null-cone condition selects $B \geq 0$ as the unconditionally admissible branch (the pointwise admissibility condition for sign-indefinite forms is stated in Section 4). Papers 18, 23, 24, and 25 declare the opposite signature $(+---)$. The mapping between conventions is $g_{\mu\nu} \rightarrow -g_{\mu\nu}$: covariant statements, scalar observables, and closed-loop holonomies are unaffected, but component-level sign relations reverse — the lapse is $+\tilde{g}_{00}$ rather than $-\tilde{g}_{00}$, the mass-shell condition reads $\tilde{g}^{\mu\nu} p_\mu p_\nu = +m^2$ rather than $-m^2$, and written signs of B -admissibility and Σ^2 statements flip. No error is committed within those papers; the note exists so that formulas are not copied across conventions without the sign map.

The disformal part of the matter metric is

$$\delta_B \tilde{g}_{\mu\nu} = B \nabla_\mu \phi \nabla_\nu \phi. \quad (116)$$

Its mixed time-space projection relative to the clock-network congruence is

$$P_\mu{}^\alpha u^\beta \delta_B \tilde{g}_{\alpha\beta} = B (P_\mu{}^\alpha \nabla_\alpha \phi) (u^\beta \nabla_\beta \phi), \quad (117)$$

so

$$P_\mu{}^\alpha u^\beta \delta_B \tilde{g}_{\alpha\beta} = B D_\mu \phi (u \cdot \nabla \phi). \quad (118)$$

The synchronization connection is the normalized mixed time-space component of the matter metric. In a local rest frame of the clock congruence, the conformal background gives

$$\tilde{g}_{00}^{(A)} = -A^2, \quad (119)$$

while the disformal correction gives

$$\delta_B \tilde{g}_{0i} = B (u \cdot \nabla \phi) D_i \phi. \quad (120)$$

The disformal sector also corrects $\tilde{g}_{00}$ at order $B(u \cdot \nabla \phi)^2$. However, in the local rest frame of the clock congruence the conformal background has no mixed time-space component, $\tilde{g}_{0i}^{(A)} = 0$. Therefore the correction to $1/\tilde{g}_{00}$ multiplies a vanishing conformal numerator and first contributes only at higher order in B . To leading order, the denominator may consistently be evaluated at $\tilde{g}_{00}^{(A)} = -A^2$.

Therefore, to leading order in B , using the convention $\tilde{\sigma}_i = \tilde{g}_{0i}/\tilde{g}_{00}$,

$$\delta \tilde{\sigma}_i \simeq \frac{\delta_B \tilde{g}_{0i}}{\tilde{g}_{00}^{(A)}} \simeq -\frac{B}{A^2} (u \cdot \nabla \phi) D_i \phi. \quad (121)$$

With the opposite convention for the synchronization one-form, the overall sign is reversed; the closed-loop invariance and exact/non-exact distinction are unaffected.

In covariant projected form this is

$$\delta \tilde{\sigma}_\mu \simeq -\frac{B}{A^2} (u \cdot \nabla \phi) D_\mu \phi, \quad (122)$$

or equivalently

$$\delta\tilde{\sigma}_\mu \simeq -\frac{B}{A^2}(u \cdot \nabla\phi)P_\mu{}^\nu \nabla_\nu\phi. \quad (123)$$

Higher-order terms include corrections from the disformal contribution to $\tilde{g}_{00}$, lapse-shift mixing, and higher powers of $B(\nabla\phi)^2/A^2$.

In a hypersurface-orthogonal 3 + 1 slicing, where $u^\mu = n^\mu$, this reduces to

$$\delta\tilde{\sigma}_i \approx -\frac{B}{A^2 N}(\partial_i\phi)(n \cdot \partial\phi), \quad (124)$$

up to lapse-shift convention and higher-order disformal corrections.

Furthermore, because the reference connection σ_{GR} is constructed using the exact same non-inertial clock congruence u^μ , any purely kinematic effects arising from the network's proper acceleration or rotation (such as Sagnac or Thomas precession) enter both $\tilde{\sigma}$ and σ_{GR} symmetrically. These kinematics therefore cancel identically in the residual connection $\Delta\sigma = \tilde{\sigma} - \sigma_{\text{GR}}$, ensuring that non-inertial cross-terms do not artificially mimic or contaminate the genuine disformal synchronization holonomy.

On the specified spatial slice this leading connection has the schematic form $\delta\tilde{\sigma} = -C d_3\phi$, where C contains the clock-frame drift, lapse factors and B/A^2 . Therefore $d_3(\delta\tilde{\sigma}) = -d_3C \wedge d_3\phi$; a uniform drift with fixed lapse, or a coefficient depending only on ϕ , gives no curvature. The relation quoted in the main text with B/A^2 outside the wedge applies when B/A^2 is a function of ϕ only and with the corresponding lapse convention. A non-exact kinetic current $J = P_{,\chi}d\phi$ does not change the exactness of $d\ln A$ and does not by itself constitute a synchronization residual; the metric and physical clock congruence must provide the connection.

This establishes the two claims used in the main text: the leading disformal synchronization representative is the projected mixed time-space component of the matter metric, and the GR-subtracted closed-loop residual is invariant under admissible synchronization re-gaugings of the fixed physical clock network.

A4. Disformal inverse and causality condition

Given $\tilde{g}_{\mu\nu} = A^2 g_{\mu\nu} + B\partial_\mu\phi\partial_\nu\phi$, define the scalar-gradient one-form $q_\mu \equiv \partial_\mu\phi$. The inverse satisfies $\tilde{g}^{\mu\nu}\tilde{g}_{\nu\sigma} = \delta^\mu_\sigma$. Ansatz: $\tilde{g}^{\mu\nu} = A^{-2}(g^{\mu\nu} + Cq^\mu q^\nu)$. Solve for C :

$$\begin{aligned} A^{-2}[g^{\mu\nu} + Cq^\mu q^\nu][A^2 g_{\nu\sigma} + Bq_\nu q_\sigma] &= \delta^\mu_\sigma \\ \Rightarrow \delta^\mu_\sigma + A^{-2}(B + A^2 C + BC(q \cdot q))q^\mu q_\sigma &= \delta^\mu_\sigma \\ \Rightarrow A^2 C + B + BC(q \cdot q) &= 0 \Rightarrow C = -\frac{B}{A^2 + B(q \cdot q)}. \end{aligned} \quad (125)$$

Thus $\tilde{g}^{\mu\nu} = A^{-2} \left[g^{\mu\nu} - \frac{(B/A^2)q^\mu q^\nu}{1 + (B/A^2)(q \cdot q)} \right]$. Lorentzian signature requires $1 + (B/A^2)(q \cdot q) > 0$.

Appendix B: Photon Phase Speed and GW–EM Constraints

In a local inertial frame ($g_{\mu\nu} = \eta_{\mu\nu}$), the photon dispersion relation is $\tilde{g}^{\mu\nu}k_\mu k_\nu = 0$. Using the disformal inverse from A4,

$$\eta^{\mu\nu}k_\mu k_\nu = \frac{(B/A^2)(q \cdot k)^2}{1 + (B/A^2)(q \cdot q)}. \quad (126)$$

For a photon with 4-momentum $k^\mu = (\omega/c, k\hat{n})$, where $k \equiv |\vec{k}|$ is not assumed equal to ω/c , and a static scalar gradient $q_\mu = (0, \nabla\phi)$, $q \cdot k = k \partial_{\hat{n}}\phi$ and $q \cdot q = |\nabla\phi|^2$. Defining $D \equiv B/A^2$, the dispersion relation gives

$$-\frac{\omega^2}{c^2} + k^2 = \frac{D k^2 (\partial_{\hat{n}} \phi)^2}{1 + D |\nabla \phi|^2}. \quad (127)$$

Solving for k^2 and extracting the phase speed $v_{\text{ph}} = \omega/k$ yields

$$v_{\text{ph}} = c \sqrt{1 - \frac{D (\partial_{\hat{n}} \phi)^2}{1 + D |\nabla \phi|^2}}. \quad (128)$$

For propagation along the gradient ($\partial_{\hat{n}} \phi = |\nabla \phi|$), this simplifies to

$$v_{\parallel} = \frac{c}{\sqrt{1 + D |\nabla \phi|^2}}. \quad (129)$$

For small D , the leading-order result is $v_{\text{ph}}/c \simeq 1 - \frac{1}{2} D (\partial_{\hat{n}} \phi)^2 + \mathcal{O}(D^2)$.

Gravitons propagate on $g_{\mu\nu}$, so $c_g = c$ exactly. The maximal fractional speed difference between photons and gravitons, for propagation perpendicular to $\nabla \phi$ ($\partial_{\hat{n}} \phi = 0$, $v_{\perp} = c$) versus along it ($\partial_{\hat{n}} \phi = |\nabla \phi|$, $v_{\parallel} = c/\sqrt{1 + D |\nabla \phi|^2}$), is

$$\frac{|c_{\gamma} - c_g|}{c} = \left| 1 - \frac{1}{\sqrt{1 + D |\nabla \phi|^2}} \right| \approx \frac{|D|}{2} |\nabla \phi|^2 \quad (\text{for small } D). \quad (130)$$

The GW170817/GRB170817A bound $|c_{\gamma} - c_g|/c \lesssim \text{few} \times 10^{-15}$ therefore requires

$$|D| |\nabla \phi|^2 \lesssim \text{few} \times 10^{-15} \quad (131)$$

along typical lines of sight today, bounding the present-day disformal coupling $B(\phi_0)$. This derivation assumes a quasi-static gradient, $q_{\mu} \simeq (0, \nabla \phi)$, appropriate to the present-day local field; it is the $\Pi = 0$ specialization of the general two-parameter cone relation of Section 8 and must not be applied to the evolving cosmological configuration, where temporal and spatial gradients coexist and the bound is evaluated along the realized photon path.

Appendix C: Glossary of Symbols

Symbol	Description	Section
$g_{\mu\nu}$	Gravitational metric tensor	2
$\tilde{g}_{\mu\nu}$	Matter/causal metric tensor	2
ϕ	The scalar time field	2
$A(\phi)$	Conformal coupling factor, $\exp(\beta_A \phi / M_{\text{Pl}})$	2
$B(\phi)$	Disformal coupling function	2
σ_B	Dimensionless field-width parameter of the strong-field disformal suppression envelope, $B(\phi) = B_0 \varphi^2 (1 + \varphi^2)^{-1} \exp(-\varphi^4 / 2\sigma_B^4)$	2.2
TEP	Temporal Equivalence Principle	1, 2
τ	Proper time defined by $\tilde{g}_{\mu\nu}$	2
H_{resid}	residual synchronization holonomy, $H_{\text{resid}}(C) \equiv \oint_C (\tilde{\sigma} - \sigma_{\text{GR}})$	3, 6
$\Delta\sigma$	GR-subtracted synchronization connection, $\Delta\sigma \equiv \tilde{\sigma} - \sigma_{\text{GR}}$	3, 6, 7, A3
u^μ, u_μ	four-velocity field of the physical clock-network congruence (upper index contravariant, lower index covariant)	3, 7, A3
$P_\mu{}^\nu$	spatial projector into the local rest space of the clock-network congruence, $P_\mu{}^\nu = \delta_\mu{}^\nu + u_\mu u^\nu$ in $(-+++)$ signature	7, A3
q_μ	scalar-gradient one-form, $q_\mu \equiv \partial_\mu \phi$	A4, B
c_g, c_γ	Speed of gravity, speed of light (photons)	5
$V(\phi)$	Scalar self-interaction potential; master form $V_{\text{matter}}(u)e^{-(u/u_s)^4} + V_0 e^{-(u_s/u)^4}$ in the dimensionless field $u = \phi / M_{\text{Pl}}$ — remains shallow across the matter domain, with a Planck-scale floor at depth	2.2, 8
$\alpha(\phi)$	Conformal coupling strength, $d(\ln A)/d\phi$	4
β_A	Dimensionless conformal coupling parameter	2
M	Suppression scale for disformal/EFT operators	4
PPN	Parametrized Post-Newtonian formalism	7
$\gamma_{\text{PPN}}, \beta_{\text{PPN}}$	Eddington PPN parameters	7
H_0	Hubble constant today	1, 8
S_8	Cosmological parameter for structure growth	1, 8
r_s	Sound horizon at recombination	8
Ξ_{AB}	One-way time asymmetry between A and B	9, 10
k^μ	Four-wavevector of a null signal	3.2
$\ln A(\phi)$	conformal factor controlling matter-frame proper time	7
Σ_μ	Temporal Shear vector, $\Sigma_\mu \equiv \nabla_\mu \ln A(\phi)$	7
C_A	covariance of conformal-factor fluctuations, $C_A(x, x') = \langle \delta \ln A(x) \delta \ln A(x') \rangle$	7
λ_T	Temporal Topology correlation length measured in clock/covariance data	7
ρ_T	Temporal Topology saturation scale; not a binary ambient-density switch	7
κ_X	Observable response coefficient for channel X, not a microscopic coupling	7

Appendix D: Terminology and Usage Glossary

Canonical Terms

Term	Usage
Temporal Topology	Spatial/covariance structure of the time field ϕ .
Temporal Shear	Active gradient $\Sigma_\mu = \nabla_\mu \ln A(\phi)$.
Screening	Suppression of local observable shear/response by $\mathcal{S}_\Sigma(\mathcal{E})$ (not applicable to global cosmological origins).
Conformal sector	$A(\phi)$, clock rates, open-path transport.
Disformal sector	$B(\phi)$, cone tilts, non-exact transport.
Synchronization holonomy	Closed-loop residual only (H_{resid}).
Clock-network covariance	GNSS/SLR/MGEX-type spatial correlation.
Response coefficient	Channel transfer parameter κ_X , distinct from the microscopic coupling.
Residual-channel candidate	Post-fit residual signal, not direct fundamental fit.
Stress test	Mixed/null/diagnostic paper.
Inherited calibration	Parameter imported from earlier paper.
No-refit prediction	External prior applied without tuning.

Sector Consistency Rules

Conformal sector. The conformal sector ($A(\phi)$) governs clock-rate, redshift, open-path, and covariance observables. Because $\nabla_\mu \ln A$ is exact, pure conformal shear does not produce closed-loop residual synchronization holonomy. Holonomy requires disformal or otherwise non-exact transport structure.

Response-coefficient rule. Fitted quantities such as κ_X , α_{sat} , and η_{resid} are observable response parameters. They are not bare scalar couplings unless a solved transfer function is supplied. The geometric projectors Γ_X are supplied by the transfer-map calculation for the primary channels (Appendix E, R12), with the wide-binary plateau closed on the selected two-branch sector (predicted $\alpha_{\text{sat}} = 0.371$ against the observed 0.366 ± 0.012 at 0.44σ , consistent with the derived projector identity $\Gamma_{\text{WB}} = 4\sqrt{2}/k \simeq 0.353$; Step 56/020).

Evidence-status rule. Every corpus paper is classified as primary evidence, consistency check, stress test, candidate application, null audit, or theoretical completion. Its result is counted accordingly in the corpus-level evidence ledger.

Appendix E: Reproducibility Record

Every numerical claim in the body of this paper traces to a registered pipeline step in `scripts/steps/`, executed in the pinned environment described in `scripts/README.md`. The table below keys each claim to its step and output artifact in `results/`; the body text cites the corresponding record identifier rather than implementation paths.

ID	Claim supported	Step	Output artifact
R1	Radial ODE closure and the nested galactic–solar–terrestrial field decomposition (Sections 2, 7): $\phi_{\text{gal}}(8 \text{ kpc}) \simeq 2.8 \times 10^{-7}$, solar perturbation at 1 AU, ambient-to-perturbation ratios, surface composition.	scripts/steps/step_01_radial_ode.py	results/step_01_radial_ode.json
R2	Two-body operator benchmark evaluation (Section 2): wide-binary shear recovery at 2646 AU, conjunction suppression $\mathcal{R}(1.6 R_{\odot}) \sim 1 \times 10^{-23}$, Saturn suppression 2.7×10^{-11} , Earth–Moon pairwise response factor $\sim 2.2 \times 10^{-15}$ (resolved nested operator, R11).	scripts/steps/step_19_operator_evaluation.py	results/step_19_operator_evaluation.json
R3	Interior rolling-floor solution on the Painlevé–Gullstrand background (Sections 2, 8): logarithmic pileup to $u \simeq 9\text{--}10$ at $1.01 r_h$, native $A \rightarrow 0$ branch selection, flatness closure to 7×10^{-14} .	scripts/steps/step_16_interior_roll.py	results/step_16_interior_roll.json
R4	Closed static eternal cosmological benchmark (Section 8): field-equation residuals below 10^{-11} ; algebraic representation of the reconstructed closed-static potential within the parametrized master family confirmed numerically to machine precision; the natural shallow choice $V_{\text{matter}} = V_{\text{rec}}$ provides the non-trivial approximate comparison across the transition region.	scripts/steps/step_12_cosmology_solution.py	results/step_12_cosmology_solution.json
R5	Volume-balance disformal reconstruction (Section 10A): $ b \sim 10^{-3}$ at $u \sim 0.75$, envelope normalization $B_0 \simeq -3 \times 10^{-3}$ on the sign-excluded branch.	scripts/steps/step_13_disformal_closure.py	results/step_13_disformal_closure.json
R6	Corrected conditional loop benchmark (Section 10A): $H_{\text{resid}} \simeq -4.33 \times 10^{-13}$ s at the stated dimensionless $B_0 = +1$; quadrature convergence, orientation reversal, spherical/exact-connection zeros and $B_0 = 0$, $\dot{u} = 0$ controls. Fixed-action normalization and common-field screening remain open.	scripts/steps/step_15_holonomy_amplitude.py	results/step_15_holonomy_amplitude.json
R7	Clock-amplitude screening baseline S_A (Section 2): computed in the companion screening paper's pipeline.	Paper 26 (TEP-C0), step_02_02	Paper 26 results.
R8	Inhomogeneous non-compact slice existence demonstration and flatness ledger (Section 8): nonlinear Lichnerowicz constraint solved on a periodic cell (universal cover R^3), residual $\sim 10^{-10}$; required sign-changing total-energy structure demonstrated both on the shifted positive- u benchmark ($\lambda_* = -2.42$ in slice units) and natively on the negative- V_{rec} void branch ($u_{\text{void}} = -0.85 < u_* = -\ln 2$, with 8,496 void cells carrying $V(u) < 0$ before any shift, $V_{\text{min}} = -0.340$, converged $\psi \in [0.9985, 1.0029]$; native unstretched-space matter curvature $^{(3)}\tilde{R} = A_{\text{sp}}^{-2(3)}R$ at fixed epoch ($D_i \ln A_{\text{sp}} = 0$) has $\int \psi^5 {}^{(3)}\tilde{R} d^3x \equiv 0$ by Gauss's theorem and physical-volume mean $ \Omega_k^{\text{native}} = 1.40 \times 10^{-4} \ll 10^{-3}$ (alongside the spatial-conformal benchmark scaling $ \Omega_k^{\text{eff}} \sim 7 \times 10^{-2}$ at $\Delta u = 0.1$ falling to $\sim 10^{-3}$ at $\Delta u = 0.02$).	scripts/steps/step_20_landscape_existence.py	results/step_20_landscape_existence.json
R9	Canonical weak-field normalization ledger (Section 2): $\delta\phi/M_{\text{Pl}} = 2\beta_A\Phi_N$, $\ln(A/A_{\infty}) = 2\beta_A^2\Phi_N$, bare unscreened matter lapse $\tilde{N}/\tilde{N}_{\infty} = e^{3\Phi_N} + O(\Phi_N^2)$ and $G_{\text{eff}}/G = 3$ for $\beta_A = -1$, with GR recovery as $S_{\Sigma} \rightarrow 0$.	scripts/steps/step_26_weak_field_lapse_ledger.py	results/step_26_weak_field_lapse_ledger.json
R10	Standard-siren source-to-detector mapping (Section 8): Einstein-frame sourcing mass $\mathcal{M}_e = A_e\tilde{\mathcal{M}}$,	scripts/steps/step_21_waveform_inference.py	results/step_21_waveform_inference.json

ID	Claim supported	Step	Output artifact
	stationary-coordinate transport $\Delta t_o = \Delta t_e$, matter-frame readout $\tilde{f}_o = f_o/A_o$ with strain invariant, inferred chirp mass $\mathcal{M}_{\text{det}} = A_o A_e \tilde{\mathcal{M}}$, inferred distances $d_L^{\text{GW}} = A_o r$ and $d_L^{\text{EM}} = (1+z)A_o r$, ratio $\Xi(z) = 1/(1+z)$; all four links symbolic-verified.		
R11	Master-action screening closure (Section 2): kinetic completion $P_X = k\sqrt{\xi} + 2\xi$ ($k \simeq 16$ fixed by a_0 ; quadratic branch dominant at all Solar-System ξ) with $\Lambda_X^4 = M_{\text{Pl}}^2 H_0^2$ gives $\mathcal{S}_\Sigma \rightarrow [1 + (g/g_t)^2]^{-1}$ on the high-gradient branch, $g_t = cH_0/(2 \beta_A) = 3.4 \times 10^{-10} \text{ m s}^{-2}$, and the nested pairwise response $\mathcal{R} = \mathcal{S}_\Sigma(X_{\text{env}})^2 y(s)$ with y the flux-conserving profile $y[1 + y^2(r_*/r)^4] = 1$ and $r_* = \sqrt{GM/g_t}$, benchmark table returns 1.0×10^{-23} (Cassini conjunction), 1.6×10^{-14} (Earth-Moon; 2.2×10^{-15} including the solar ambient in the vertex factors), 2.7×10^{-11} (Saturn — hierarchical $\mathcal{R} = y^3 \sim s^4$, corresponding to $\delta a \simeq 3.5 \times 10^{-15} \text{ m s}^{-2}$ against the $\sim 5 \times 10^{-13}$ ephemeris bound), 1.2×10^{-21} (terrestrial shear), and the wide-binary transition scale at zero per-system free parameters (comparable-mass pairs: $\mathcal{R} = \mathcal{S}_{\text{env}}^2 y \sim s^{4/3}$, the exponent selected by the 341k-binary forward model).	scripts/steps/step_27_master_action_screening_closure.py	results/step_27_master_action_screening_closure.json
R12	Channel-response transfer map (Section 7): $\kappa_X = \beta_A \mathcal{S}_X \Gamma_X$ evaluated across the six primary channels (GNSS, Cepheid, millisecond pulsar, wide binary, galactic, LLR/flyby). Derived projectors: $\Gamma_{\text{GNSS}} = \beta_A $ (quadratic covariance channel), $\Gamma_\mu = 5/\ln 10$, $\Gamma_{\text{MSP}} = 1$, $\Gamma_{\text{gal}} = \Gamma_\mu(1+z)^{\beta_A \Delta u}$, $\Gamma_{\text{LLR}} = 1$ as a unit range normalization, with $\Gamma_\Sigma(g_{\text{lunar}}) = 1.6 \times 10^{-14}$ retained as the R11 force benchmark rather than a clock-to-range derivation; wide-binary saturation amplitude closed on the selected two-branch sector (predicted $\alpha_{\text{sat}} = 0.371$ against the observed 0.366 ± 0.012 at 0.44σ ; projector identity $\Gamma_{\text{WB}} = 4\sqrt{2}/k \simeq 0.353$; Step 56/020).	scripts/steps/step_05_gamma_all_channels.py	results/step_05_gamma_all_channels.json
R13	Canonical lapse admissibility, evolving CMC initial slice, and preferred-foliation khronon static maximal slice (Section 8): Step 21 retains the Hamiltonian source at $\Pi = 0$, solves $(-D_h^2 + q)N = C$ with $\langle N \rangle_{\sqrt{h}} = 1$ on 16^3 and 48^3 grids ($N > 0$, relative residual $< 10^{-10}$, $C = \partial_t \mathcal{K} > 0$), and shows that a purely canonical scalar shift requires $\Pi_{\text{can}}^2 < 0$ (motivating the noncanonical sector), whereas the preferred-foliation khronon/cuscuton drift term $P_{\text{drift}} = -\mu_{\text{kh}}^2 \sqrt{2X} (2XP_{\text{drift},X} - P_{\text{drift}} \equiv 0$, $S_{\text{drift}} = -3\mu_{\text{kh}}^2 \Pi < 0$) solves the exact unshifted static maximal-slicing equation $(-D_h^2 + q_{\text{kh}})N = 0$ ($\partial_t \mathcal{K} = 0$) with $N \in [0.9990, 1.0005] > 0$ ($N = 16$; $[0.9992, 1.0004]$ at $N = 48$), residual $< 10^{-10}$, and strictly positive real drift $\mu_{\text{kh}}^2 \Pi = \frac{2}{3} M_{\text{Pl}}^2 \mu_0 > 0$; Step 28 solves the coupled $\mathcal{A}_{ij} \neq 0$ momentum/shear sector ($\psi \in [0.75, 1.81]$).	scripts/steps/step_21_lapse_solvability.py, scripts/steps/step_28_momentum_shear_sector.py	results/step_21_lapse_solvability.json, results/step_28_momentum_shear.json
R14	On-shell landscape evolution (Section 8): the scalar field is solved from its elliptic equation $D^2 u = V_u - \rho_m + \lambda_c$ on the matter landscape (bordered Newton, mean-field gauge, iterated against the Lichnerowicz solve) rather than prescribed, giving initial data on-shell at 10^{-8} with constraint residual 10^{-12} ; the same integration machinery then produces a monotonic drift over $\Delta u \simeq 3.4$ (lookback $z \lesssim 28$) without reversal, and constrained evolution on the step-21 maximal-slice eigen lapse holds the	scripts/steps/step_51_onshell_landscape_evolution.py	results/step_51_onshell_landscape_evolution.json

ID	Claim supported	Step	Output artifact
	Hamiltonian residual near 10^{-5}. Three variants isolate the earlier failure: prescribed wells, an uphill momentum kick against the ambient slope, and the two-zone lapse rescaling. A nested-landscape variant (broad envelope plus embedded wells, one global scalar solve) realizes the Rule-22 hierarchy on a single slice — parent-ambient/exterior-ambient offset $\Delta u \simeq +0.022$ with level-dependent drift — and evaluates the screening operator $P_{,X} - 1 \simeq 5 \times 10^{-6}$ (normalized on the slice's own drift rate; conservative since that branch inflates H_0), i.e. the benchmark is in the unscreened weak-gradient regime — screening responds to temporal-field steepness, not spatial compactness.		
R15	Binary-pulsar scalar-dipole transmission and strong-equivalence-principle bounds (Section 7): Step 69 evaluates both (i) the massless fixed-$r = a$ unscreened-sensitivity unit-term control $P = X + X X /\Lambda_X^4$ ($T_{\text{amp}} = 0.0121$ and tightest margin 0.529 on J1738+0333 when stellar-to-orbit interior screening between R_{NS} and a is omitted) and (ii) the selected two-branch sector $P_{,X} = k\sqrt{\xi} + 2\xi$ ($k = 16.03$) with shell-impedance screening across the compact-body-to-wave-zone profile ($T_{\text{amp}}^{\text{imp}} \simeq a/r_* = 9.2 \times 10^{-7} \text{--} 1.4 \times 10^{-5}$, 2.26×10^{-6} on J1738+0333), clearing all binary-pulsar $\dot{P}_b$ bounds across the full EOS sensitivity bracket by amplitude margins of 2.8×10^3 to 3.9×10^4 at $K_D = 0.5$ (tightest: $2,817 \times$ on J1738+0333 s_{hi}; $996 \times$ to 1.39×10^4 at $K_D = 4.0$) and the J0337+1715 hierarchical $\mathcal{R} = y^3$ SEP channel at $\eta_{\text{pred}} = 2.54 \times 10^{-14} \ll 2.6 \times 10^{-6}$ (margin $\sim 10^8 \times$).	scripts/steps/step_69_dipole_transmission.py	results/step_69_dipole_transmission.json
R16	Standard-siren invariant, continuous worldline LLR/redshift reconciliation, and intrinsic-population bookkeeping (Section 8): the dimensionless inspiral invariant $I = G_{\text{loc}} \mathcal{M} f / c^3$ is tracked through locally measured constants at both endpoints — a source-local observer recovers the standard chirp mass for screened systems ($M_{\text{loc}} = \widetilde{M}(1 + \alpha_A \alpha_B) / (1 + \alpha_e^2) \rightarrow \widetilde{M}$), so the $(1+z)^{-1}$ detector-mass map is a transport statement (coordinate frequency conserved on the static background), with $\Xi(z) = A_e / A_o$. The frame-consistent chirp identity $M_{\text{det}} = (A_e / A_o)(1 + \alpha_A \alpha_B) / (1 + \alpha_o^2) \widetilde{M}$ is verified symbolically. On the continuous two-branch + quartic radial profile ($P_{,X} = k\sqrt{\xi} + 2\xi$, zero thin-shell approximation; Step 76), the operative response on the Cassini-compatible screened branch — the quartic normalization used for the Solar-System flux profile — resolves to the static tangent $T_{\text{tan}} = 1.2 \times 10^{-8}$ at $10^8 R_{\oplus}$ (finite-excursion secant below the declared field-reporting floor at the same radius and at $10^{10} R_{\oplus}$), bounding the local drift under strictly constant M_{Pl} in S_{grav} and $G_{\text{loc}} = G_* A^2(\phi)(1 + \alpha_{\text{amb}}^2)$ to $\dot{A}/A _{\text{loc}} \lesssim 8.4 \times 10^{-19} \text{ yr}^{-1}$ and $\dot{G}_{\text{loc}}/G_{\text{loc}} _{\text{LLR}} \lesssim 1.7 \times 10^{-18} \text{ yr}^{-1}$, more than four orders of magnitude below both the Williams et al. bound $4 \times 10^{-13} \text{ yr}^{-1}$ and the Hofmann–Müller re-analysis result $(7.1 \pm 7.6) \times 10^{-14} \text{ yr}^{-1}$; the reference-quartic comparison branch supplies the conservative finite-excursion secant ceiling $T_{\text{cont}} \equiv \Delta u_{\text{int}} / \Delta \bar{u}_{\text{amb}} = 1.99 \times 10^{-3}$, i.e. $\dot{G}_{\text{loc}}/G_{\text{loc}} \lesssim 2.85 \times 10^{-13} \text{ yr}^{-1} < 4 \times 10^{-13} \text{ yr}^{-1}$ (this unscreened comparison ceiling satisfies the Williams et al. bound only; the operative screened	scripts/steps/step_70_siren_invariant.py, scripts/steps/step_71_intrinsic_mass_drift.py, scripts/steps/step_73_sn_luminosity_bound.py; Paper 26 (TEP-C0) script s/steps/step_03_11_sn_luminosity_drift_profile.py	results/step_70_siren_invariant.json, results/step_71_intrinsic_mass_drift.json, results/step_73_sn_luminosity_bound.json; Paper 26 results/step_03_11_sn_luminosity_drift_profile.json

ID	Claim supported	Step	Output artifact
	branch satisfies both LLR analyses) (plus the two-branch scalar-force self-energy drift $2H_0 y_{\text{ib}}(1 \text{ AU}) = 2.10 \times 10^{-15} \text{ yr}^{-1} \ll 4 \times 10^{-13} \text{ yr}^{-1}$, with <code>solve_ivp</code> Keplerian ODE integration confirming $\tilde{r}/\tilde{r}_0 = 0.99688$ versus the unscreened $T = 1$ shrinkage $\tilde{r}/\tilde{r}_0 = A^{-2} = 0.20186$), while explicit <code>solve_ivp</code> null-geodesic ray-tracing in the canonical $(3+1)$ ADM matter metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(\phi(t, \mathbf{x}))\Pi_{\mu\nu}$ $(d\tilde{s}^2 = -N_{\text{TEP}}^2(\mathbf{x})c^2 dt^2 + A_{\text{sp}}^2(t, \mathbf{x})\gamma_{ij}(\mathbf{x})dx^i dx^j$, with stationary baryon-sourced lapse $N_{\text{TEP}}(\mathbf{x}) = \exp(-u_{\text{grav}}(\mathbf{x}))$ so $\partial_t \ln N_{\text{TEP}} = 0$ and no secular $\mathcal{O}(1)$ potential cliff develops between galaxies and the IGM, and matter-frame ruler-drift factor $A_{\text{sp}}(t, \mathbf{x}) = \exp(\beta_A u_{\text{drift}}(t, \mathbf{x})) = \exp(-u_{\text{drift}}(t, \mathbf{x}))$ on static gravitational space dx with $\partial_t \ln A_{\text{sp}} = -\partial_t u_{\text{drift}} = +H_{\text{drift}} > 0$) with full static-observer 4-velocity normalization $\tilde{\omega} = -\tilde{u}^\mu k_\mu = E/N_{\text{TEP}}$ proves the universal differential-geometric redshift identity $\ln(1+z) = \int_{t_e}^{t_o} \partial_t \ln A_{\text{sp}} dt + \int_{x_e}^{x_o} \partial_x \ln N_{\text{TEP}} dx$ $= [1 - f_{\text{well}}(1 - T_{\text{cosmo}})]\Delta\tilde{u}_{\text{amb}} + \delta u_{\text{env}},$ recovering 100.00% of the Hubble law ($\ln 1.1 = 0.09531$ at $z = 0.1$; Step 70) for IGM-to-IGM and at the physical $10^8 R_\oplus$ screening scale ($f_{\text{IGM}} = 1 - f_{\text{well}} = 1.000000$; 99.72% for two halo-scale wells with $f_{\text{IGM}} = 0.9972$, 94.13% for 20 intervening halo-scale wells with $f_{\text{IGM}} = 0.9421$, and linear Hubble scaling across the Lyman-α forest lookback sweep $\Delta \in [0.02, 0.20]$) without invoking a running Planck mass or $f_{\text{well}} = 1$. For source populations, if interiors track the ambient drift by fraction ϵ, characteristic masses drift as $(1+z)^{3\epsilon}$ and the discriminant runs as $(1+z)^{3\epsilon-1}$ (null at $\epsilon = 2/3$, reversed at $\epsilon = 1$). The Chandrasekhar-channel diagnostic assumes $L \propto G^{-3/2}$, giving $\Delta m = -7.5\epsilon \log_{10}(1+z)$. Step_73 records the residual-floor estimate $\epsilon \lesssim 0.05\text{--}0.10$; Paper 26's fixed-$z_T = 5$ M1 profile likelihood returns $\epsilon < 0.150$ at 3σ ($\Delta\chi^2 = 805.8$ at $\epsilon = 1$, best fit $\epsilon = -0.05$) for SN Ia progenitors under its stated distance model and Chandrasekhar luminosity prescription, and the host-assembly calculation (<code>results/outputs/audit_epsilon_bbh_derivation.json</code>) yields $\epsilon_{\text{eff}} \simeq 0.004$ for deep-well SN Ia hosts versus 0.24–0.52 for field-spiral/dwarf BBH hosts. Paper 22 independently establishes the BBH population likelihood on GWTC, resolving the global profile optimum at $\hat{\epsilon} = 0.0$ ($\Delta \ln L = +2.32$ over stationary GR) consistent with the derived progenitor host-assembly range.		
R17	Static ambient-boundary response (Sections 2, 8), unit-term control: <code>step_53</code> solves the kinetic/quartic radial boundary-value problem with central flux regularity and an enforced outer Dirichlet value. <code>Step_76</code> separates linearized susceptibility from finite-excursion secants and explicitly varies both the quartic branch and outer radius. For the Earth at the reference coupling and an outer radius of $10^{10} R_\oplus$, the tangent is 0.9966 while the secant at imposed $\delta u = 2.5 \times 10^{-11}$ is 1.5×10^{-5}; at the Cassini-compatible coupling the same outer-radius readings are 0.210 and 9.3×10^{-9}. With that coupling but imposed comparison interfaces at $235 R_\oplus$ and $23,500 R_\oplus$, the finite secants instead reach 0.99998 and 0.9831. The massless-vacuum control returns unit response: the falloff is potential- and domain-dependent, not a universal loss of clock amplitude	<code>scripts/steps/step_76_ambient_transmission.py</code>	<code>results/step_76_ambient_transmission_two_branch.json</code> ; <code>results/step_76_ambient_transmission.json</code> (unit-term control)

ID	Claim supported	Step	Output artifact
	inside Earth. A separate local gradient benchmark evaluates the cross-term of isolated Earth and Solar profiles at 1 AU: their aligned-to-antialigned kinetic-stiffness span is 0.345 relative to Earth's isolated value. The comparison interfaces and local gradient bracket are not a self-consistent coupled Earth–Sun solution, nor a frequency-dependent lunar-clock, GNSS or cosmological transfer. On the selected two-branch operator, Step 76 also solves the same sources, potential and boundaries directly. At $10^8 R_\oplus$ with the reference quartic coupling, the Earth tangent is 0.6536 and the finite-excursion secant at $\delta u = 2.5 \times 10^{-11}$ is 0.00199. At $10^{10} R_\oplus$, the Earth, Sun and Cepheid-envelope finite responses fall below the declared field-reporting resolution; a computed zero tangent is reported as a numerical value rather than a universal exact bound. The selected massless-vacuum control transmits with unit tangent and secant. Comparison interfaces at $235 R_\oplus$ and $23,500 R_\oplus$ retain near-unit reference response, so suppression depends on the potential and matched outer domain. A 1,200/2,400/4,800-point refinement at the measurable $10^8 R_\oplus$ boundary gives tangents 0.65346/0.65357/0.65359, independently reproduced by small-excursion differences of the nonlinear solved profiles. The static depth ratio S_A remains distinct from both transmission and clock covariance.		
R18	Inhomogeneous landscape stability (Section 8): positive restricted finite-cell spectra and independent ambient bounds are retained. Step 79 also records (i) the complete second-variation audit on the canonical reconstructed potential (<code>completed_canonical_reconstructed_coupled_audit</code>), showing that retaining $+\rho_*(x)\frac{d^2(e^{-u})}{du^2} = +\rho_*(x)e^{-u}$ at the Step-12 cell-mean density $\langle \rho_* \rangle = 2 \text{ rhob_half}$ flips the unprojected lowest eigenvalue from -0.4389 (bare V''_{rec} alone) to $\lambda_0 = +0.4123--0.4127 > 0$ ($N = 16, 24$), (ii) a conditional quartic calculation that re-solves the Hamiltonian geometry with a prescribed scalar profile and offset, and (iii) a jointly on-shell quartic calculation (<code>joint_on_shell_quartic_two_branch_coupled_audit</code>) that solves both the nonlinear two-branch scalar Euler–Lagrange equation and the Lichnerowicz Hamiltonian constraint simultaneously to $< 3.1 \times 10^{-12}$ ($N = 16, 24$, unprojected coupled $\lambda_0 = +0.5624--0.5633 > 0$, $\lambda_1 = +378.95--381.67$, all-twist bound $+0.4662--0.4668 > 0$). In all three unprojected audits, the metric response has an explicit volume constraint $q_{\text{vol}}^T \delta \psi = 0$ solved by a bordered inverse, and the all-twist bound uses the half-wave lattice gap rather than the periodic-cell gap. These finite-grid constrained-operator benchmarks do not establish full-action continuum stability.	<code>scripts/steps/step_79_inhomogeneous_eigenmodes.py</code>	<code>results/step_79_inhomogeneous_eigenmodes.json</code>
R19	Unified matter metric, spatially covariant ADM/DHOST and local khronon gravitational action on static space, GW170817 shared-cone verification, PPN slip, SLACS/ESO 325 lens-dynamics consistency, and standard-siren consistency (Sections 2.2, 7, 8): symbolic verification of $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ ($d\tilde{s}^2 = -N_{\text{TEP}}^2(\mathbf{x})c^2 dt^2 + A_{\text{sp}}^2(t, \mathbf{x})\gamma_{ij}(\mathbf{x})dx^i dx^j$) and $S_{\text{grav}} = \frac{1}{2}M_{\text{Pl}}^2 \int d^3x dt \sqrt{\gamma} N_{\text{GR}}[R_{\text{scalar}}^{(3)}(\gamma) + A_{\text{sp}}^{-1}R_{\text{TT}}^{(3)}(\gamma) + (A_{\text{sp}}/A_{\text{loc}}^2)(K_{ij}K^{ij} - K^2)] = \frac{1}{2}M_{\text{Pl}}^2 \int d^3x dt \sqrt{\gamma} N_{\text{GR}}[A_{\text{sp}}^{-1}R^{(3)}(\gamma) +$	<code>scripts/steps/step_80_shared_lapse_action_derivation.py</code>	<code>results/step_80_shared_lapse_action_derivation.json</code>

ID	Claim supported	Step	Output artifact
	$2(A_{\text{sp}}^{-1} - 1)\gamma^{ij}D_i \ln N_{\text{GR}} D_j \ln N_{\text{GR}} + \tilde{K}_{ij}\tilde{K}^{ij} - \tilde{K}^2]$ (where the quadratic SVT pieces $\sqrt{\gamma}N_{\text{GR}}R_{\text{scalar}}^{(3)} = -2(\nabla\Phi_N/c^2)^2$ and $\sqrt{\gamma}N_{\text{GR}}R_{\text{TT}}^{(3)} = -\frac{1}{4}\gamma^{kl}\partial_k h_{ij}^{\text{TT}}\partial_l h_{ij}^{\text{TT}}$ are reproduced identically at quadratic order by the strictly local khronon acceleration operator $a_i a^i = \gamma^{ij}D_i \ln N_{\text{GR}} D_j \ln N_{\text{GR}}$ of Blas, Pujolàs & Sibiriyakov 2010 without any non-local Poisson inverse), proving (i) $\delta S_{\text{grav}}/\delta u_{\text{grav}} \equiv 0$ and $\delta S_{\text{grav}}/\delta A_{\text{sp}} \equiv 0$ in the quasistatic limit $K_{ij} \rightarrow 0$ (preserving the Poisson and scalar source equations without Jordan-frame degeneracy), (ii) identical GW/EM wave operator $\square_{\text{TEP}} = -(N_{\text{TEP}}c)^{-2}\partial_t^2 + A_{\text{sp}}^{-2}(t, \mathbf{x})\gamma^{ij}\partial_i\partial_j$ with $c_{\text{GW}}(t, \mathbf{x}) = c_\gamma(t, \mathbf{x}) = c N_{\text{TEP}}(\mathbf{x})/A_{\text{sp}}(t, \mathbf{x})$ at every event ($\Delta t_{\gamma\text{-GW}} \equiv 0.0$ s for GW170817 at $z = 0.0098$, vs. 6.92×10^5 yr on an unshared tensor operator) and shared refractive index $n(x) \simeq 1 - 2\Phi_N/c^2 - \beta_A u_{\text{grav}}(x)$ at fixed epoch ($A_{\text{sp}} = 1$), (iii) PPN slip $\gamma_{\text{PPN}} - 1 = -2\beta_A^2 S_\Sigma/(1 + 2\beta_A^2 S_\Sigma) < 0$ ($\gamma_{\text{PPN}} - 1 \simeq 4.32 \times 10^{-8} \ll 2.3 \times 10^{-5}$ at $1.6 R_\odot$ on the two-branch sector, with exact ray-integrated Earth–Sun–Saturn Cassini Doppler $\gamma_{\text{PPN}} - 1 _{\text{Doppler}} = 9.01 \times 10^{-8}$ and conjunction-differential Shapiro $\gamma_{\text{PPN}} - 1 _{\text{Shapiro}} = 3.74 \times 10^{-7} \ll 2.3 \times 10^{-5}$, zero-gradient regulator $\epsilon_{\text{reg}} = 10^{-3}$, intrinsic moving-source PPN coefficients $\alpha_1^{\text{int}}(1.6 R_\odot) = -8.64 \times 10^{-8}$, $\alpha_2^{\text{int}}(1 \text{ AU}) = -1.47 \times 10^{-5}$ and CMB-projected observables $\alpha_1(1.6 R_\odot) = -1.31 \times 10^{-13}$, $\alpha_2(1 \text{ AU}) = -2.23 \times 10^{-11} \ll 4 \times 10^{-9}$ and galaxy-scale lensing slip at ESO 325-G004 and the SLACS ensemble, where the idealized zero-ambient vacuum baseline $y_{\text{tb}}(R_{\text{Ein}}) = 0.152$ ($\gamma_{\text{SMP}} = 0.767$ at $X_{\text{group}} = 0$) is superseded in the realized nested cosmic hierarchy (Section 2.3) by ambient group/filamentary screening of the incremental scalar response ($y_{\text{eff}} = 1.6 \times 10^{-3}$–$7.3 \times 10^{-3}$ and $\gamma = 0.986$–0.997 on the $M_h = 3 \times 10^{13}$–$3 \times 10^{14} M_\odot$ group-halo profile with $X_{\text{group}} = 131$–611, or $y_{\text{eff}} = 0.007$–0.104 and $\gamma = 0.83$–0.98 across effective-ambient $X_{\text{group}} = 3$–100, with the 1σ floor $\gamma \geq 0.88$ requiring only $X_{\text{group}} \geq 8.1$, $y_{\text{eff}} \leq 0.068$; Step 30 operator), consistent with both Collett et al. 2018 $\gamma_{\text{SMP}} = 0.97 \pm 0.09$ and the SLACS massive-ETG ensemble $\langle \gamma_{\text{SMP}} \rangle = 0.98 \pm 0.07$ ($\gamma_{\text{pred}} = 0.972$–$0.981$ at $M_h = 3 \times 10^{13} M_\odot$, 0.01–0.11σ; Cao et al. 2017; Shajib et al. 2021)), and (iv) constant WKB tensor measure $\sqrt{A_{\text{sp}}^{+1} \cdot A_{\text{sp}}^{-1}} \equiv 1$ on static space ($\sqrt{\gamma} = 1$) eliminating FLRW Hubble friction and preserving $1 + z = A_o/A_e$ and $\Xi(z) = d_L^{\text{GW}}/d_L^{\text{EM}} = 1/(1 + z) \neq 1$.		

The full step registry, execution order, and pinned dependency versions are documented in `scripts/README.md`; the complete output set in `results/` also archives the intermediate diagnostics for steps not cited in the body.

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