Operational Quantum Gravity in Practice: Spectral Stiffness, Matter Scaling, Equivalence, and Cosmology without Dark Energy

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Abstract

Operational Quantum Gravity (OQG) identifies the completed, state-dependent Standard-Model stress response as the physical system represented macroscopically by Einstein geometry. This paper is an educational construction of that system in practice. It distinguishes the full spectral kernel $\Pi^{R}_{TT}(\omega, k; \rho)$ from its static long-wavelength coefficient $A_{2,E}[\rho]$, explains what the matter-and-vacuum baseline contains, and follows the nested states that occur when an epoch background, a localized source, and an applied preparation act on the same body. The complete conserved energy-momentum tensor then supplies inertial, passive, and source mass; matched tensor loading gives the local equivalence principle; construction-specific kernels determine clock and ruler changes; causal unloading separates free fall from support; and signal transfer is counted independently from intrinsic matter response. On OQG's homogeneous covariant branch, the energy–stiffness ratio follows exactly from common scaling. Relaxation is entropic in nature: irreversible entropy production reduces the available scale-supporting inventory while conserving total energy. The effective time constant is reconstructed observationally; its microscopic origin remains to be calculated. With $H_0 = 69\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$, a two-parameter quadratic effective-time law fitted to 32 cosmic chronometers gives $\chi^2 = 11.84$ for 30 degrees of freedom. Without refitting, the same response predicts all six DESI DR2 Alcock-Paczyński measurements with $\chi^2 = 6.60$ and every marginal residual below 1.6σ. The result is a practical matter-first route from Standard-Model response to relativity and cosmology without a physical Dark Energy density or a nonzero cosmological integration constant.

Keywords: operational quantum gravity; Standard Model stress response; spectral stiffness; matter scaling; equivalence principle; cosmology without physical Dark Energy

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1. Introduction

Relativity organizes comparisons made with physical clocks, rulers, light signals, accelerometers, and freely moving bodies with extraordinary accuracy [8]. The practical question addressed here is what physical quantum system supplies the standards and responses that those geometrical relations describe, and how that system should actually be used in a calculation.

Every measured interval is realized by Standard-Model matter. A clock is a repeatable transition or oscillation; a ruler is an equilibrium separation or correlation length; an accelerometer is a material body carrying stress [7]. OQG therefore places the physical state first and treats Einstein geometry as the exact long-wavelength comparison map generated by that state. Matter tells matter how to scale. Geometry is just bookkeeping.

The physical system is the Standard-Model spectral fabric: the complete matter-and-vacuum response that exists before a particular support, drive, clock, ruler, or signal protocol is selected. It contains the conserved stress of gauge fields, fermions, the Higgs sector, kinetic and binding energy, pressure and shear, boundaries and contact terms, occupations and correlations, thresholds and condensates, and measurable connected vacuum polarization and fluctuations. It is not an ether and it is not an extra substance inside spacetime. It is the full Standard-Model baseline from which physical responses are prepared.

Its central constitutive quantity must therefore carry its state. The complete spectral object is $\Pi^R_{TT}(\omega, k; \rho)$, where ω is frequency, k is wave number, and ρ is the density operator describing the physical state. $A_{2,E}[\rho]$ is not that whole function: it is the coefficient extracted from its static, small-k slope. Position r, source mass M, temperature T, composition, and preparation enter $A_{2,E}$ only through the state ρ unless one writes them explicitly as labels, for example $A_{2,E}(r; M) \equiv A_{2,E}[\rho(r; M)]$. This convention makes state dependence visible without mistaking the long-wavelength coefficient for the full spectral kernel.

The same body can occupy several nested states. The homogeneous epoch supplies a baseline; a localized source establishes a local ambient state relative to that epoch; support, acceleration, heating, or another boundary condition prepares an additional deviation; and causal release removes only that additional preparation. This hierarchy is essential because it prevents the source response, the applied load, the signal path, and the receiver protocol from being counted twice.

With those states named, the equivalence principle becomes a calculation rather than an unexplained identification. Translation symmetry gives a complete isolated body one conserved four-momentum, so its inertial response and leading long-range source share one coefficient. Real applied forces prepare real tensor stress. Supported and accelerated laboratories are locally equivalent when their applicable ambient states, force distributions, boundary tractions, and complete loading deviations match.

The trace-free infrared completion retains Einstein's successful field-equation structure while introducing one global integration constant. OQG selects its zero branch. A homogeneous vacuum-energy offset is not promoted into a connected local source, although measurable vacuum response, polarization, condensates, and state-dependent fluctuations remain inside the completed spectral fabric. This distinction removes the vacuum catastrophe from the local source ledger without deleting the quantum vacuum from physics.

The paper ends with the principal quantitative application. Within OQG's homogeneous discharge description, relaxation is entropic in nature. Covariant scaling fixes the energy–stiffness relation exactly on the common-scale branch; observations reconstruct the effective time constant and its redshift dependence. Using $H_0 = 69\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ only as the dimensional normalization, 32 cosmic chronometers determine two coefficients. Those coefficients are then carried into all six DESI DR2 Alcock-Paczyński measurements without refitting, giving $\chi^2 = 6.60$ and marginal residuals below 1.6σ.

Sections 2 and 3 define the spectral fabric, the $A_{2,E}[\rho]$ notation, and the hierarchy of epoch, ambient, prepared, and unloaded states. Sections 4 through 9 develop complete-body mass, loading equivalence, clocks, rulers, free fall, measurement protocol, force, work, and the special-relativistic branch. Sections 10 through 12 develop irreversible state evolution and the cosmological tests. Section 13 collects the accomplishments and the remaining microscopic calculations. The central proposition is unchanged throughout: one completed Standard-Model response supplies the physical system, while geometry records its long-wavelength comparisons.

2. The Standard-Model Spectral Fabric and State-Dependent Stiffness

The objective of this section is to define the minimum established OQG structure needed by every practical application that follows. The full causal normalization, Standard-Model matching, finite-frequency continuation, and fixed-measure Einstein-equivalent construction have already been derived in the foundational OQG manuscript and its Technical Appendices [6]. They are cited here rather than proved again; the present task is to make their physical use transparent.

The physical starting point is a Standard-Model quantum state, represented by the density operator ρ_{SM}, and its complete conserved energy-momentum tensor $T^{\mu\nu_{\mathrm{SM,tot}}}$. Complete means complete: gauge fields, fermions, the Higgs sector, kinetic and binding energies, pressure, shear, boundaries, and the local terms required by conservation are included before the response is calculated. Separating these contributions can be useful for bookkeeping, but the physical source is their conserved total.

The first inherited statement is therefore conservation of the complete Standard-Model tensor:

$$\partial_\mu T^{\mu\nu_{\mathrm{SM,tot}}} = 0. \tag{1}$$

Averages such as $\langle \mathcal{O} \rangle_\rho = \mathrm{Tr}(\rho\mathcal{O})$ describe what an observable $\mathcal{O}$ measures in the chosen physical state. Equation (1) says that energy and momentum are redistributed within the complete system; they do not disappear when the system changes its internal form.

OQG calls the completed spectrum of allowed stress response the spectral fabric. The name fabric refers to a baseline of physical susceptibility, not to a new medium. It is the Standard-Model matter-and-vacuum system whose connected stress correlations and conservation-required local terms supply inertia, loading response, clocks, rulers, and the long-range comparison law represented macroscopically by Einstein geometry.

The baseline includes both ordinary matter and the measurable quantum vacuum. Gauge and fermion fields, Higgs expectation values, real vacuum polarization, condensates, connected zero-point fluctuations, kinetic and binding energy, pressure, shear, boundaries, occupations, and correlations can all change a response function and therefore belong in ρ. By contrast, an arbitrary state-independent shift of the homogeneous vacuum energy does not change a connected correlator and is not a separately measurable local source. The vacuum is retained as response; only the unobservable additive offset is excluded.

This distinction is what makes the word fabric useful. The fabric is not "empty space," and it is not only the particles visible in a detector. It is the entire conservation-completed Standard-Model response available in the declared state. A later source or applied load does not create a second fabric; it prepares a new state of the same one.

The response calculation is the quantum counterpart of finding the compliance of an engineering structure. One first assembles the complete stiffness matrix, including the terms required by conservation. Conservation leaves directions that cannot represent an independent physical deformation. Those null directions are removed, and only the remaining physical block is inverted. A real stress then goes into that causal inverse, and a physical matter response comes out.

The Greek letter Π denotes the stress-response matrix. Its labels $A = (\mu\nu)$ and $B = (\rho\sigma)$ identify pairs of tensor components. The superscript R means **retarded**: the response occurs after the disturbance, never before it. The connected part describes correlations between stress disturbances. The contact part contains local terms that arise when the complete tensor is varied and are required for conservation. The completed response is their sum:

$$\Pi^{R_{\text{comp}}} = \Pi^{R_{\text{conn}}} + \Pi^{R_{\text{contact}}}, \qquad p_\mu \Pi_{\text{comp}^{R\,\mu\nu,\rho\sigma}}(p) = 0. \tag{2}$$

The second relation in Equation (2) is the Ward identity [3, 4]. In this context, "Ward" is not a new force or substance; it is the name given to the conservation condition obeyed by the response. Omitting the contact contribution can violate that condition even when the separated-point correlation has been calculated correctly.

The closed-time-path construction cited in Refs. [12, 15, 17, 22] is the real-time bookkeeping method used to calculate this causal response in an interacting quantum state. It provides the retarded ordering; it does not introduce another physical field.

Let $\mathcal{P}_{\text{phys}}$ remove the Ward-null directions. The projected response and its causal inverse D^R then act only on the physical stress subspace:

$$\Pi^{R_{\text{phys}}} = \mathcal{P}_{\text{phys}} \Pi^{R_{\text{comp}}} \mathcal{P}_{\text{phys}}, \qquad \delta q_{\text{op},A}(x) = \int d^4y\, D^R_{AB}(x, y; \rho)\, \delta T^{B_{\text{phys}}}(y). \tag{3}$$

Equation (3) is the matter-first ordering used throughout this paper. The applied Standard-Model stress $\delta T^{B_{\text{phys}}}$ is the physical input. The retarded compliance D^R maps that input into the operational response $\delta q_{\text{op},A}$. Geometry is the long-wavelength representation of the completed response; it is not assumed as the microscopic cause.

The long-range sector is isolated by the transverse-traceless (TT) projection. "Transverse" means perpendicular to the propagation direction, and "traceless" removes the scalar trace. The full spectral object $\Pi^R_{TT}(\omega, k; \rho)$ records response versus frequency ω and wave number k in the state ρ [19]. Writing the static spatial momentum in energy units as $Q = \hbar c k$, the Euclidean Kubo coefficient $A_{2,E}[\rho]$ is extracted from the small-Q slope:

$$\rho_2(\omega, k; \rho) = -2\,\mathrm{Im}\,\Pi^R_{TT}(\omega + i0, k; \rho), \qquad A_{2,E}[\rho] = -\frac{\partial \Pi_{TT,E}(0, Q; \rho)}{\partial Q^2}\bigg|_{Q=0}. \tag{4}$$

The word Kubo identifies the standard response-theory rule that extracts a measurable coefficient from correlation data. Equation (4) also fixes the notation. Π_{TT}^{R} depends spectrally on ω and k. $A_{2,E}[\rho]$ is the static two-derivative stiffness left after setting $\omega = 0$ and taking the $k \to 0$ slope; it therefore carries the state ρ, not an independent residual k argument. If the state is generated by a radius, source mass, temperature, composition, or preparation, those variables may be displayed as $A_{2,E}(r; M, T, \ldots) \equiv A_{2,E}[\rho(r; M, T, \ldots)]$. Higher powers of k belong to higher-gradient coefficients rather than to $A_{2,E}$ itself. This Euclidean extraction requires a state admitting the static limit, the stated continuation, and a local gradient expansion. Driven or nonstationary states require the full retarded response and an explicit limiting procedure; the static formula is not applied to them automatically.

Within this static regime, the same stiffness can be written as a local contribution plus the accumulated TT spectrum,

$$A_{2,E}[\rho] = A_{\mathrm{loc}}[\rho] + \int_0^\infty \frac{d\epsilon}{\epsilon}\,\mathcal{B}_{TT}(\epsilon; \rho), \qquad A_{2,E}(E_s, X) = E_s^2 a_{TT}(X). \tag{5}$$

Equation (5) shows both parts of the baseline. $A_{\mathrm{loc}}[\rho]$ contains the completed local and Ward-contact contribution. The spectral integral contains the accumulated TT weight from the state's connected excitations and fluctuations. The energy scale E_s is the physical scale of the state, while X collects dimensionless couplings, particle and bound-state content, thresholds, condensates, occupations, correlations, and spectral shape. A state change can therefore alter both the overall scale and the dimensionless response.

For the homogeneous cosmological branch, the corresponding fixed-state-data dilation tangent is proportional to the enthalpy density, $h = \varepsilon + p$. Section 10 derives and interprets that result. It is mentioned here only to identify the same state dependence that later enters the cosmological history; it is not used as a second derivation.

For a declared state ρ admitting this static expansion, the static coefficient produces the massless long-wavelength compliance

$$D_{TT,E}(0, k; \rho) = \frac{1}{A_{2,E}[\rho](\hbar c k)^2 + O((\hbar c k)^4)}, \qquad G_{\mathrm{comp}}[\rho] = \frac{\hbar c^5}{16\pi A_{2,E}[\rho]}. \tag{6}$$

The first part of Equation (6) keeps the full logical dependence visible. The inverse-k^2 behavior gives a long-range inverse-distance response, while $A_{2,E}[\rho]$ fixes its residue. The second part converts that same microscopic stiffness into the macroscopic compliance coefficient conventionally written as Newton's constant for that state. The physical direction is Standard-Model state $\rho \to$ completed response $\to A_{2,E}[\rho]$ $\to G_{\mathrm{comp}}[\rho]$; measured gravity is not inserted to manufacture the microscopic spectrum.

The OQG manuscript calculates the interacting high-state stiffness by completing the free, soft, hard, electric/Higgs, local-matching, and magnetostatic sectors through the stated order:

$$A_{2,E} = A_{2,E}^{(0)} + A_{2,E}^{(g)} + A_{\mathrm{hard}^{(g^2)}} + A_{E/H}^{(g^2)} + A_{R,\mathrm{match}}^{(g^2)} + A_{M^{\mathrm{NP}}}. \tag{7}$$

These terms are not separate gravitational sources. They are calculational parts of one completed Standard-Model stiffness. For the declared high-state input set and matching prescription, the stored result is [6]

$$\frac{A_{2,E}[\rho_T(T,X)]}{(k_BT)^2} = 0.260056643133723 + 0.066623718018839\,\xi_H + 0.002999279573124\,c_3^{\mathrm{NP}} + 0.000799379975567\,c_2^{\mathrm{NP}}. \tag{8}$$

The displayed digits preserve the reproducible ledger; they are not an uncertainty claim. The coefficient calculation is complete through $O(g^2)$ under the stated prescription. The renormalized Higgs-curvature input ξ_H and the finite three-dimensional magnetostatic inputs $c_{3^{\mathrm{NP}}}$ and $c_{2^{\mathrm{NP}}}$ retain their declared status. Equation (8) is a high-state Standard-Model result, not a numerical prediction of the present measured value of G.

Translation symmetry fixes the zero-momentum normalization of the complete-body stress form factor:

$$\lim_{q\to 0}\langle p+q/2,\alpha'|T^{\mu\nu_{\mathrm{SM,tot}}}(0)|p-q/2,\alpha\rangle = 2p^\mu p^\nu \delta_{\alpha'\alpha}, \qquad A(0)=1. \tag{9}$$

Equation (9) says that a complete isolated body's total conserved energy-momentum is the coefficient seen by a sufficiently long-wavelength probe. Internal binding and stress can redistribute that total, but they do not create a second independent monopole. Section 4 uses this inherited normalization to compare inertial mass with the leading long-range source.

The fixed-measure WTDiff completion then writes the long-wavelength comparison law in Einstein-equivalent form,

$$G_{\mu\nu}[g^{\mathrm{op}}] + \Lambda_{\mathrm{int}} g^{\mathrm{op}}_{\mu\nu} = \frac{8\pi G_{\mathrm{comp}}}{c^4} T_{\mu\nu}. \tag{10}$$

The left-hand side of Equation (10) is the Einstein-equivalent WTDiff bookkeeping representation of the response [1, 2]. The right-hand side contains the physical Standard-Model source. The tensor structure is Einstein equivalent, but the matter response remains ontologically prior.

The quantity Λ_{int} is the global integration constant that appears as Einstein's cosmological constant in the recovered equation. A state-independent vacuum shift does not act as a connected local source, and the physical branch used throughout this paper is

$$\Lambda_{\mathrm{int}} = 0. \tag{11}$$

Equation (11) is not a fitted Dark Energy component and is not shorthand for a cancellation between enormous vacuum terms. It is the selected zero-cosmological-constant branch on which the finite-body, relativistic, and homogeneous results of this paper are developed [2].

The inherited foundation can now be read as one physical sequence:

$$\rho_{\mathrm{SM}} \to T^{\mu\nu_{\mathrm{SM,tot}}} \to \{\rho_2, \mathcal{B}_{TT}, A_{\mathrm{loc}}\}_{\mathrm{completed}} \to A_{2,E} \to D^R \to g^{\mathrm{op}_{\mu\nu}}. \tag{12}$$

The Standard-Model state and its complete conserved stress response do the physics. The Kubo stiffness supplies the long-range compliance. The Einstein-equivalent field equation is the resulting macroscopic comparison map, and the cosmological integration constant is fixed on the zero branch.

This section has not rederived the foundational OQG calculation. It has defined the physical objects used by the rest of the paper and retained the two inherited quantitative accomplishments needed below: the completed interacting high-state stiffness through $O(g^2)$ under the declared prescription, and the Einstein-equivalent response with $\Lambda_{\mathrm{int}} = 0$. The following sections now show how the same state-dependent coefficient is used for baselines, finite bodies, loading, clocks, rulers, relativity, and cosmological matter-standard evolution.

3. Epoch, Ambient, Prepared, and Unloaded Baselines

The objective of this section is to turn $A_{2,E}[\rho]$ into an unambiguous working notation. A material response has meaning only after its reference state is named. OQG therefore uses a nested hierarchy rather than one universal "unloaded" value.

The four states used throughout the paper are written

$$\begin{aligned} A_{2,E}^{\text{epoch}}(t) &\equiv A_{2,E}\big[\rho_{\text{epoch}}(t)\big], & A_{2,E}^{\text{ambient}}(x,t \mid \mathcal{S}) &\equiv A_{2,E}[\rho_{\text{ambient}}(x,t \mid \mathcal{S})], \\ A_{2,E}^{\text{prepared}}(x,t \mid \mathcal{S},\mathcal{B}) &\equiv A_{2,E}\big[\rho_{\text{prepared}}(x,t \mid \mathcal{S},\mathcal{B})\big], & A_{2,E}^{\text{unloaded}}(\tau) &\equiv A_{2,E}[\rho_{\text{unloaded}}(\tau)]. \end{aligned} \tag{13}$$

In Equation (13), t labels cosmological epoch, x labels the local event, S specifies the source configuration, B specifies the applied boundary preparation, and τ is proper time along the body's history. The superscripts do not create four different stiffnesses. They identify four evaluations of the same functional $A_{2,E}[\rho]$.

The epoch state is the coarse-grained Standard-Model baseline common to an otherwise isolated system at time t. The ambient state is what exists locally after a specified source and environment have established their response. The prepared state includes the further support, drive, heating, confinement, pressure, or boundary traction applied to a particular body. The unloaded state is the state reached after that additional preparation has been removed causally; it remains referenced to the local ambient state and may retain tides or irreversible history.

This hierarchy also answers when explicit variables should appear. In homogeneous work, $A_{2,E}\big[\rho_{\text{epoch}}(t)\big]$ is sufficient. Near a source, $A_{2,E}[\rho_{\text{ambient}}(x,t \mid S)]$ is the relevant coefficient. If spherical symmetry lets x be represented by radius r and the source family by mass M, one may write $A_{2,E}(r;M)$ as shorthand for $A_{2,E}[\rho_{\text{ambient}}(r;M)]$. The notation exposes physical dependence without claiming that r or M is a new spectral coordinate. The spectral coordinates remain ω and k in $\Pi^{R}_{TT}(\omega,k;\rho)$.

All applied forces that prepare the same body must be combined before the residual response is calculated:

$$\begin{gathered} f_{\text{ext,tot}}{}^{\nu} = f_{\text{support}}{}^{\nu} + f_{\text{drive}}{}^{\nu} + f_{\text{other}}{}^{\nu}, \\ \rho_{ambient} \xrightarrow{f_{\text{ext,tot}},\, t_{\text{tot}}{}^{i}} \rho_{\text{tot}} \rightarrow T_{\text{SM,tot}}{}^{\mu\nu}[\rho_{\text{tot}}]. \end{gathered} \tag{14}$$

The complete prepared state in Equation (14), rather than separate labels attached to its causes, is the input to the residual response. Support, drive, heating, confinement, and other preparations may reinforce, oppose, or redistribute one another inside the body. The ambient state is the starting density operator in this sequence; it is not another applied force added to the total external force density.

Ratios between successively nested baselines then compose exactly on any common scalar branch:

$$\frac{A_{2,E}^{\text{prepared}}(x,t|\mathcal{S},\mathcal{B})}{A_{2,E}^{\text{epoch}}(t)} = \frac{A_{2,E}^{\text{ambient}}(x,t|\mathcal{S})}{A_{2,E}^{\text{epoch}}(t)} \frac{A_{2,E}^{\text{prepared}}(x,t|\mathcal{S},\mathcal{B})}{A_{2,E}^{\text{ambient}}(x,t|\mathcal{S})}, \qquad \Delta\lambda_{\text{total}} = \Delta\lambda_{\text{source}} + \delta\lambda_{\text{load}}. \tag{15}$$

Equation (15) is an identity because each numerator becomes the next denominator. The epoch supplies the underlying baseline, the source establishes the local ambient baseline, and the preparation supplies the final state. Directional loads remain tensorial; only after a common scalar reduction has been derived may the logarithmic increments be added. This is the no-double-counting rule.

The practical accomplishment is a state ledger that can be followed without guessing. State the full kernel when frequency or wavelength matters; state $A_{2,E}[\rho]$ when the static long-wavelength coefficient is meant; display t, x, r, M, T, S, or B when they identify the state family; and omit an argument only after the applicable state has been declared in the surrounding sentence or equation. The same convention is used in every section that follows.

4. Inertial Mass, Long-Range Source, and Infrared Uniqueness

This section connects the field-level result of Section 2 to the motion of an ordinary body. The question is simple even though the tensor notation can obscure it: does the quantity that resists acceleration also determine how strongly the body produces and responds to the long-range gravitational field?

Three names are commonly used for the coefficients involved. Inertial mass is the coefficient relating an applied force to the body's acceleration. Passive gravitational mass describes the body's response to an existing gravitational field, while source mass is the coefficient producing the body's leading long-range field.

OQG does not begin by assuming that these three coefficients are equal. Their equality follows from using the complete conserved stress tensor of the body together with the single massless transverse-traceless response established in Section 2.

A *complete body* means the whole stationary system: particles, binding fields, internal pressure, container walls, and any other stresses required to keep the system together. If only one component is retained, the energy and momentum assigned to that incomplete subsystem need not be conserved, and the mass comparison can fail before the physics has even been tested.

Translation symmetry supplies a conserved four-momentum. For a localized system with no stress-energy flowing through its outer boundary,

$$P^{\nu} = \frac{1}{c}\int_{\Sigma_t} d^3\,x\,T^{0\nu}, \qquad \partial_{\mu}T^{\mu\nu} = 0. \tag{16}$$

Here, $T^{\mu\nu}$ is the complete stress tensor and Σ_t is a constant-time slice through the body. The first expression adds the locally distributed energy and momentum; the second states that none is created or destroyed inside the closed system. Together they make P^{ν} independent of the chosen time slice.

In the body's rest frame,

$$P^{\mu} = \left(\frac{E_0}{c}, \mathbf{0}\right), \qquad -P_{\mu}P^{\mu} = M_0^2c^2, \qquad E_0 = M_0c^2. \tag{17}$$

The invariant M_0 is the body's inertial mass. Its rest energy E_0 includes constituent masses, kinetic energy, binding energy, and the energy stored in the stresses that stabilize the body. It is therefore a property of the complete equilibrium state, not merely the sum of the masses of isolated ingredients.

At wavelengths much larger than the body, a probe cannot resolve those internal ingredients separately. Their collective coupling to the stress tensor is summarized by form factors. At zero momentum transfer, conservation fixes the leading form factor:

$$\langle P'|T^{\mu\nu}(0)|P\rangle = 2P^{\mu}P^{\nu}A(q^2) + \text{terms proportional to } q, \qquad A(0) = 1. \tag{18}$$

The function $A(q^2)$ records how the body's energy and momentum are distributed when it is examined at spatial resolution set by q. The value $A(0) = 1$ says that an infinitely long-wavelength probe sees the entire conserved four-momentum. Internal structure changes the finite-q terms, but it cannot renormalize away the total energy-momentum of the complete body.

Internal pressure does contribute locally to T^{ij}, so it cannot simply be discarded point by point. For a stationary, isolated, mechanically stable system, however, the positive and negative supporting stresses balance when the *whole* body is integrated. This is the von Laue condition. Applied to the leading static source combination, it gives

$$\int d^3x\, T^{ij} = 0, \qquad M_{\mathrm{src}} = \frac{1}{c^2}\int d^3x\left(T^{00} + T^{ii}\right) = \frac{E_0}{c^2} = M_0. \tag{19}$$

The repeated spatial index i is summed. The first relation does not say that pressure is absent. It says that the integrated internal stresses of a stable complete object balance. The second relation then shows that the coefficient of its leading static field is the same M_0 already fixed by conserved four-momentum [16, 23]. Omitting a wall, binding field, or stabilizing stress would destroy that cancellation and create a false mismatch.

At a specified epoch t_0, the ambient state far from localized bodies fixes the long-wavelength compliance. Denote its two-derivative coefficient by $A_{2E,\infty} \equiv A_{2,E}\left[\rho_{\mathrm{epoch}}(t_0)\right]$. In the static limit, the kernel and its Green function have the form

$$\mathcal{K}_\infty = A_{2E,\infty}(\hbar c)^2(-\nabla^2) + O(\nabla^4), \qquad \mathcal{G}_\infty(r) = \frac{1}{4\pi A_{2E,\infty}(\hbar c)^2 r} + O(r^{-3}). \tag{20}$$

The kernel K_∞ specifies how difficult it is to produce a long-wavelength deformation of the declared epoch state. Its inverse, G_∞, tells how that response propagates from a source. The term $1/r$ is the familiar long-range behavior. Higher derivatives carry additional powers of momentum and therefore fall faster with distance. The infinity label is only the boundary condition for this isolated-source problem; the underlying coefficient remains $A_{2,E}\left[\rho_{\mathrm{epoch}}(t_0)\right]$.

Consequently, two well-separated complete bodies have the leading interaction energy

$$V_{12}(r) = -\frac{G_\infty M_1 M_2}{r}\left[1 + O\left(\frac{R_1^2+R_2^2}{r^2}\right)\right]. \tag{21}$$

Here, G_∞ is the coupling determined by the ambient response coefficient, while R_1 and R_2 characterize the bodies' sizes. The correction term represents finite-size and higher-form-factor effects. It becomes negligible when the separation r is much larger than either body.

Now place body 2 in the slowly varying potential Φ_1 produced by body 1. The field exerts a force with the same complete-body coefficient that appears in the inertial response:

$$\mathbf{F}_2 = -M_2\boldsymbol{\nabla}\Phi_1, \qquad \frac{d\mathbf{p}_2}{dt} = M_2\mathbf{a}_2 + O(v^2/c^2). \tag{22}$$

Eliminating the common factor M_2 gives

$$\mathbf{a}_2 = -\boldsymbol{\nabla}\Phi_1 + O\left(\frac{v^2}{c^2}, \frac{R_2^2}{\ell_\Phi^2}, \text{tidal response}\right). \tag{23}$$

The scale ℓ_{Φ} is the distance over which the external field changes appreciably. Equation (23) is the operational content of universality at leading order: bodies with different compositions follow the same acceleration because the mass multiplying the applied field is the same mass multiplying their resistance to acceleration. Composition, spin, shape, and internal structure can enter only through the displayed subleading corrections, which are separately testable.

The result can therefore be stated compactly as

$$M_{\text{inertial}} = M_{\text{passive}} = M_{\text{source}} = \frac{E_0}{c^2}. \tag{24}$$

This equality includes changes in internal energy. If a complete body absorbs, releases, or rearranges an amount of energy ΔU, then

$$M = M_{\text{ref}} + \frac{\Delta U}{c^2}. \tag{25}$$

The body's inertia, passive response, and leading source strength change together because all three are readings of the same complete conserved stress tensor.

In this context, *infrared* means low momentum and correspondingly long distance. Section 2 established one massless transverse-traceless pole in the completed Standard-Model stress response. A pole is the mathematical signature of a disturbance that can propagate without acquiring a finite range; its residue fixes the strength with which conserved stress excites that disturbance.

Once that pole, its tensor projector, and its residue are fixed, the leading long-range response is fixed. Local changes to a material body can alter its higher form factors and multipole moments, but they cannot manufacture a second independent $1/r$ law while preserving the same completed Ward identities and the same ambient state.

This gives a precise sense in which an additional fundamental graviton would be redundant within OQG [14]. A second massless tensor field coupled to the same conserved stress would generically introduce a second long-range pole or change the observed residue. To remain observationally indistinguishable, it would have to decouple or reproduce the response that the completed Standard-Model kernel already supplies. This is an infrared matching statement, not a claim that every possible high-energy mathematical description has been ruled out.

The equality in Equation (24) follows from four connected facts. Translation symmetry fixes the conserved four-momentum of a complete body. The zero-momentum stress form factor is normalized to that complete four-momentum, the integrated stresses of a stationary stable body balance, and the common ambient massless pole couples to that same completed stress tensor.

The leading result is therefore not an independently imposed equivalence principle. It is a consequence of the conservation law and response structure already established.

The boundary is equally important. The argument fixes the common leading mass coefficient and the universal long-range acceleration. It does not erase finite-size structure. Higher form factors, spin couplings, tidal response, material thresholds, and other composition-dependent corrections remain part of the low-energy phenomenology. Those terms test the limits of the leading approximation; they do not alter the identity of the mass that appears at zero momentum and at leading order in the long-range field.

5. Proper Loading and the Local Equivalence Principle

The physical question in this section is whether gravity and ordinary acceleration act differently on matter. In OQG, the answer is determined by the state actually prepared inside the body, but that preparation must be measured from the correct local baseline. Matter in the present epoch first inherits the current homogeneous Standard-Model state. A gravitating source such as Earth then establishes the local ambient response about which a nearby body is prepared. Support or acceleration adds real momentum transfer, boundary traction, pressure, and shear to that ambient state. Those Standard-Model interactions create the additional tensor loading from which the clock, ruler, and inertial deviations must be calculated.

The practical rule is direct: a force is a force. Support against gravity, an accelerating floor, a suspension point, an electromagnetic actuator, and any other applied force all contribute to one total tensor state before its response is evaluated. The same center-of-mass acceleration can nevertheless produce different internal states if the force is applied through different boundaries. A column pushed from below is compressed, while the same column hanging from above is in tension. Equal acceleration alone is therefore enough only for an ideal pointlike laboratory; an extended laboratory must also reproduce the force distribution and boundary traction.

An accelerometer summarizes the local loading by the proper acceleration of its material element,

$$u^{\mu} = \frac{dx^{\mu}}{d\tau}, \qquad a^{\mu} = u^{\nu}\nabla_{\nu}u^{\mu}, \qquad a_{\mathrm{prop}} = \sqrt{a_{\mu}a^{\mu}}. \tag{26}$$

The symbol u^{μ} is the element's four-velocity, τ is the time counted by its local clock, and a_{prop} is the acceleration that a physical instrument reports. The covariant derivative in Equation (26) is the Einstein-equivalent bookkeeping description. The instrument reading itself is produced microscopically by Standard-Model forces transmitted through the accelerometer.

To identify what an applied force changes, compare the prepared body with the ambient state that exists at the same location and epoch before the additional support or drive is applied:

$$\Delta T_{L}^{\mu\nu}(x) = \left(T_{\mathrm{SM,tot}^{\mu\nu}}(x)\right)_{\mathrm{prepared}} - \left(T_{\mathrm{SM,tot}^{\mu\nu}}(x)\right)_{\mathrm{ambient}}. \tag{27}$$

Equation (27) retains the full tensor while fixing the correct subtraction. Energy density, pressure, directional stress, binding fields, supports, and actuator forces are not split into competing mechanisms. They are components of one prepared state evaluated relative to its source-defined local ambient state. The ambient contribution is not recreated from the support force, and the support response is not inserted again as a separate gravitational contraction.

The physical calculation follows the preparation in its actual causal order:

$$\begin{aligned} \rho_{\mathrm{ambient}} \overset{f_{\mathrm{ext}},\, t^{i}}{\rightarrow} \rho_{prep} \rightarrow T_{\mathrm{SM,tot}^{\mu\nu}}\left[\rho_{prep}\right] \rightarrow \{\Pi_{\mathrm{comp}^{R}}, \Pi_{\mathrm{comp,E}}\}_{\rho_{prep}} \\ \rightarrow D^{R}\left[\rho_{prep}\right] \rightarrow \mathcal{R}_{\mathrm{matter}}\left[\rho_{prep}\right]. \end{aligned} \tag{28}$$

Here f_{ext} represents applied force density and t^{i} represents boundary traction. They carry the ambient density operator $\rho_{ambient}$ into the prepared density operator ρ_{prep}. Its complete stress tensor determines the completed response kernels and their causal inverse, which then determine the physical matter response $\mathcal{R}_{matter}$. The response is evaluated once from the completed prepared state, while the ambient source response remains the baseline rather than a second applied force.

It follows that a laboratory supported against gravity and a laboratory accelerated by another force have the same physical response when their complete preparations match:

$$\begin{gathered}\text{same force distribution} + \text{same boundary traction} + \text{same complete Standard-Model state} \\ \Rightarrow \text{same clock, ruler, and inertial response.}\end{gathered} \tag{29}$$

This is the local equivalence principle expressed as a statement about matter rather than an unexplained identification of two acceleration numbers. Gravity does not require an additional microscopic deformation after the supported state has already been prepared. If the complete loading is the same, the Standard Model has no second label by which to distinguish the two laboratories.

Free fall is the complementary physical preparation. Releasing a supported body removes its boundary traction. The change cannot occur everywhere inside a finite object at one coordinate instant; an unloading disturbance propagates through the material by ordinary causal Standard-Model interactions. After that transient has passed, the additional uniform support stress is absent. The body does not return to an asymptotic or universal state: it remains on the local ambient baseline established by the source and the current epoch. Its internal binding stress remains, and spatial variation of the external field still produces tidal loading across its finite size. The distinction is therefore

$$\begin{aligned}\text{supported gravity} \quad &\equiv \text{matched applied acceleration,} \\ \text{free fall} \quad &\equiv \text{removal of uniform support loading.}\end{aligned} \tag{30}$$

The detailed force-balance equations, traction boundary terms, loading diagnostic, supported-column example, causal release sequence, and tidal control parameters are retained in Technical Appendix B.1–B.3. The result needed by the main argument is now explicit: supported matter carries an additional load relative to its local ambient state, ideal freely falling matter does not carry that uniform support deviation, and identical ambient states plus identical total loading deviations produce identical physical matter response.

6. Clock and Ruler Response of Loaded Standard-Model Matter

Section 5 established what must be matched: the complete physical loading of the body. This section identifies what is measured. A clock is a repeatable transition or oscillation, and a ruler is an equilibrium separation or correlation length. Neither is an abstract coordinate interval. The engineering procedure is to specify the clock transition, specify the ruler's equilibrium condition, prepare the complete applied stress, and calculate the resulting change through the material response.

Different clock and ruler constructions need not have identical sensitivities to temperature, pressure, shear, or applied force. They nevertheless respond within the same completed Standard-Model state. Mechanical strain, binding stress, and environmental sensitivity are already part of that state; none can be omitted and then added again as an independent OQG contraction.

For clock construction a, let $E_{a,+}[\rho]$ and $E_{a,-}[\rho]$ be the two energy levels used to count cycles in state ρ. Its intrinsic angular frequency is

$$\omega_a[\rho] = \frac{E_{a,+}[\rho] - E_{a,-}[\rho]}{\hbar}. \tag{31}$$

Equation (31) says exactly what the clock is: a selected Standard-Model energy difference expressed as a cycle rate. When loading changes the complete stress tensor, the corresponding first-order clock shift can be written

$$\delta\ln\omega_a(x) = \int d^4y\, \mathcal{K}^R_{a,\mu\nu}(x,y)\, \delta T_{\mathrm{SM,tot}^{\mu\nu}}(y). \tag{32}$$

The retarded clock kernel $\mathcal{K}^R_{a,\mu\nu}$ tells how strongly that particular transition responds to each component of applied stress and how quickly the response arrives. Its microscopic construction combines the transition's stress sensitivity, obtained through the Feynman-Hellmann relation [11], with the completed causal compliance D^R from Section 2. An actual calculation or calibration must therefore supply the chosen transition, its state, and its stress-sensitivity coefficients. Equation (32) is not a universal numerical shift for every clock.

A ruler is treated just as concretely. Let $U_a(R, \hat{n}; \rho)$ be the complete binding or free energy of two fiducial features separated by R in direction $\hat{n}$. The equilibrium length L_a occurs at the minimum of that energy, and a small load moves the minimum according to

$$\left.\frac{\partial U_a}{\partial R}\right|_{R=L_a} = 0, \qquad \delta L_a(\hat{n}) = -\left(\left.\frac{\partial^2 U_a}{\partial R^2}\right|_{L_a}\right)^{-1} \left.\frac{\partial\, \delta U_a}{\partial R}\right|_{L_a}, \qquad \frac{\delta L(\hat{n})}{L} = n_i n_j \epsilon_{ij}. \tag{33}$$

The curvature $\partial^2 U_a / \partial R^2$ is the ruler's restoring stiffness. A shallow minimum moves more than a steep one under the same perturbation. The final expression projects the material strain tensor ϵ_{ij} onto the ruler's direction, making directional response explicit.

The corresponding causal ruler response is

$$\epsilon_{ij}(x) = \int d^4y\, \mathcal{C}^R_{ij,\mu\nu}(x,y)\, \delta T_{\mathrm{SM,tot}^{\mu\nu}}(y). \tag{34}$$

The material kernel $\mathcal{C}^R_{ij,\mu\nu}$ contains the binding-energy response, elastic compliance, pressure sensitivity, polarizability, and any other environmental dependence of the selected ruler. A quantitative experiment must supply or measure those material coefficients. The kernel does not replace ordinary elasticity; it organizes those Standard-Model effects into one causal tensor response.

For a material that is initially isotropic in its local ambient equilibrium state, the static ruler response to an additional load separates naturally into a volume-like part and a directional shear part:

$$\epsilon_{ij} = C_0 \frac{\delta T_{kk}}{3} \delta_{ij} + C_2 \left(\delta T_{ij} - \frac{\delta T_{kk}}{3} \delta_{ij}\right). \tag{35}$$

The coefficient C_0 measures the response to the spatial trace, which changes all directions equally. The coefficient C_2 measures the response to the traceless stress, which distinguishes one direction from another. The local ambient material may therefore be isotropic even though a directional applied force produces an anisotropic deviation from it.

For a uniaxial stress $\delta T_{ij} = \sigma m_i m_j$, the lengths parallel and perpendicular to the applied direction change by

$$\frac{\delta L_\parallel}{L} = \frac{\sigma}{3}(C_0 + 2C_2), \qquad \frac{\delta L_\perp}{L} = \frac{\sigma}{3}(C_0 - C_2). \tag{36}$$

Equation (36) makes an important point visible without additional algebra. Longitudinal-only contraction is not automatic. It occurs only for the special material condition $C_0 = C_2$; otherwise a transverse response accompanies the longitudinal one. Directionality comes from the applied stress and the tensor compliance, not from assigning a preferred direction to the local ambient state.

A clock can be decomposed by the same physical logic. Its first-order local response may depend separately on energy density, volume-like stress, and directional stress:

$$\delta \ln \omega_a = K_{a,E}\,\delta T^{00} + K_{a,0}\frac{\delta T_{kk}}{3} + K_{a,2} Q_a^{ij}\left(\delta T_{ij} - \frac{\delta T_{kk}}{3}\delta_{ij}\right). \tag{37}$$

The tensor Q_a^{ij} describes the orientation sensitivity of the selected transition. The coefficients $K_{a,E}$, $K_{a,0}$, and $K_{a,2}$ are construction dependent; atomic, molecular, optical, nuclear, and mechanical clocks need not assign the same residual weight to each stress component.

When a supported laboratory and an accelerated laboratory have the same applicable ambient state and identical complete loading profiles, the same kernels act on the same tensor deviation. Their clock and ruler responses relative to that ambient state are therefore equal:

$$\left.\frac{\omega_a}{\omega_{a,amb}}\right|_g = \left.\frac{\omega_a}{\omega_{a,amb}}\right|_a, \qquad \left.\frac{L(\hat{n})}{L_{amb}}\right|_g = \left.\frac{L(\hat{n})}{L_{amb}}\right|_a \quad \text{for every } \hat{n}. \tag{38}$$

Equation (38) is the observable consequence of the loading equivalence derived in Section 5. Here the subscript amb denotes the same local ambient clock or ruler reference for the two matched preparations. The equation applies to the same construction in matched ambient and loaded states. It does not claim that all clocks or all materials have identical residual sensitivities, or that equal proper acceleration removes a difference between two genuinely different ambient source states.

After support is removed, the body approaches the freely falling local ambient reference only after its transient response has relaxed. The applicable reference follows the source-established baseline along the trajectory; it is not the asymptotic vacuum or a universal state. If ϵ_{tr} denotes the remaining unloading transient and χ_{tide} the residual tidal loading, then

$$\rho_{\text{final}} = \rho_{\text{ambient}} + O(\chi_{\text{tide}}, \epsilon_{\text{tr}}) \Rightarrow \begin{cases} \omega_{a,\text{ff}}/\omega_{a,amb} = 1 + O(\chi_{\text{tide}}, \epsilon_{\text{tr}}), \\ L_{\text{ff}}(\hat{n})/L_{amb} = 1 + O(\chi_{\text{tide}}, \epsilon_{\text{tr}}). \end{cases} \tag{39}$$

Permanent heat, excitation, radiation loss, plastic strain, or damage would remain in ρ_{final} and must not be called unloading. Equation (39) concerns reversible return to the local ambient state at the event being considered. As the body moves through a nonuniform source response, that ambient reference can itself change along the trajectory.

There is also a narrower homogeneous comparison used later in cosmology. Along a self-similar path $\rho(\lambda)$ through Standard-Model state space, hold the dimensionless construction data fixed or calculate their change separately. The normalized clock, ruler, stiffness, and signal-scale ratios are then

$$\frac{\omega_a[\rho(\lambda)]}{\omega_a[\rho(\lambda_0)]} = \frac{L_a[\rho(\lambda)]}{L_a[\rho(\lambda_0)]} = \left(\frac{A_{2,E}[\rho(\lambda)]}{A_{2,E}[\rho(\lambda_0)]}\right)^{1/2}, \qquad \frac{c[\rho(\lambda)]}{c[\rho(\lambda_0)]} = \frac{A_{2,E}[\rho(\lambda)]}{A_{2,E}[\rho(\lambda_0)]}. \tag{40}$$

The equal normalized ratios in Equation (40) do not make frequency and length the same observable. On the covariant comparison branch, the accompanying change of c preserves the local dimensionless ratio $\omega L/c$. Equation (40) states only that specified clocks and rulers can inherit one common underlying spectral scale along the declared homogeneous state path $\rho(\lambda)$. It is a cross-state comparison whose reference $\rho(\lambda_0)$ must always be named; it is not permission to replace a local source baseline by the epoch state after unloading. Under directional loading, the full tensor responses in Equations (32)-(37) remain necessary.

The accomplishment of this section is therefore twofold. It gives a construction-specific route from complete applied stress to measurable clock and ruler changes relative to the applicable local ambient state, and it proves that an isotropic ambient state can respond directionally when the applied tensor stress is directional. The homogeneous $A_{2,E}[\rho(\lambda)]$ relation supplies the epoch-scale baseline needed by the later cosmological comparison. Numerical coefficients for particular low-energy clocks and rulers still require actual Standard-Model material calculations or calibration. Signal propagation and remote comparison are separate parts of the measurement protocol and enter only in Section 8.

7. Causal Unloading, Free Fall, and Tidal Response

The objective of this section is to distinguish removal of an applied support from removal of the ambient state. A source establishes the local baseline described in Section 3. Support adds a real boundary preparation. Release removes that additional preparation through an ordinary causal Standard-Model transient, while field gradients can still produce a finite, anisotropic tidal response across an extended body.

Let $z^\mu(\tau)$ describe the center-of-energy trajectory after every nongravitational support has been removed. In the Einstein-equivalent infrared bookkeeping map, ideal free fall satisfies

$$a_{\mathrm{CM,ff}^\mu} \equiv \frac{Du^\mu}{D\tau} = 0, \qquad F_{\mathrm{support}^\mu} = 0, \qquad t_{\mathrm{support}^{\hat{\imath}}} = 0. \tag{41}$$

The covariant derivative compactly records the long-wavelength comparison; it is not an additional microscopic force. The physical statement is the zero accelerometer reading. No floor, tether, pressure gradient, or external field is transferring the force that would hold the body stationary. The ordinary binding stresses that keep the body intact remain, but the additional stress and boundary traction required for support do not.

Removing a support is not instantaneous throughout an extended object. If a boundary element at y is released at its local proper time $\tau_{\mathrm{rel}}(y)$, the removed traction and the induced change of the interior stress can be written

$$\begin{aligned} \delta t^{\hat{\imath}}(y) \quad &= -t_{\mathrm{supp}^{\hat{\imath}}}(y)\, \Theta\big[\tau_y - \tau_{\mathrm{rel}}(y)\big], \\ \delta T_{\mathrm{trans}^{\mu\nu}}(x) \quad &= \int d^4y\, \mathcal{G}^{R\,\mu\nu}_{\hat{\imath}}(x,y)\, \delta f_{\mathrm{rel}^{\hat{\imath}}}(y), \qquad \mathcal{G}^R(x,y) = 0 \quad \text{for } x^0 < y^0. \end{aligned} \tag{42}$$

Here $\delta f_{\mathrm{rel}^{\hat{\imath}}}$ is an equivalent localized release force density, and $\mathcal{G}^R$ is the completed retarded material response. Equation (42) says that each part of the body responds only after the unloading disturbance reaches it. Elastic waves, internal oscillations, mode conversion, and damping are the physical process by which the old supported state becomes the new freely falling state.

After that disturbance has crossed the body, the complete local tensor has the general form

$$\begin{aligned} &T_{\mathrm{late}^{\mu\nu}} = T^{\mu\nu}_{ambient} + \Delta T_{\mathrm{tide}^{\mu\nu}} + \Delta T_{\mathrm{hist}^{\mu\nu}}, \\ &\Delta T_{\mathrm{hist}^{\mu\nu}} = 0 \quad \text{on the ideal reversible branch.} \end{aligned} \tag{43}$$

The reference tensor is the complete equilibrium state established locally by the specified source within the current epoch, not an empty tensor and not a universal state at infinity. The tidal term is the finite-size response to the source gradient. The history term retains any heat, excitation, radiation loss, plastic strain, fracture, or other irreversible change produced before or during release. Unloading removes the applied support; it does not erase the ambient response or a Standard-Model state that has genuinely changed.

On the reversible branch, after the transient has relaxed and when tides are small, the local clock and ruler approach the ambient values appropriate to their present event on the free-fall trajectory. Their earlier record is nevertheless retained in the accumulated clock phase:

$$\begin{aligned} \frac{\omega_{a,\mathrm{ff}^{\mathrm{local}}}}{\omega_{a,amb}} &= 1 + O(\chi_{\mathrm{tide}}, \epsilon_{\mathrm{tr}}, \delta_{\mathrm{hist}}), \qquad \frac{L_{\mathrm{ff}^{\mathrm{local}}}(\hat{n})}{L_{amb}(\hat{n})} = 1 + O(\chi_{\mathrm{tide}}, \epsilon_{\mathrm{tr}}, \delta_{\mathrm{hist}}), \\ \varphi_a(\tau_2) - \varphi_a(\tau_1) &= -\int_{\tau_1}^{\tau_2} d\,\tau\, \omega_a[\rho(\tau)]. \end{aligned} \tag{44}$$

The small quantity ϵ_{tr} denotes the residual unloading transient, while δ_{hist} denotes a retained irreversible clock or ruler change. Equation (44) separates present condition from accumulated history and from the changing ambient source baseline. Two clocks can recover the same instantaneous rate after reunion at the same location and in the same ambient state while still displaying different accumulated phases because they counted cycles through different earlier states.

Let T_{ij} denote the locally measured tidal tensor: the first spatial gradient of the source-established relative acceleration across the laboratory. The difference between support and tide is exposed by expanding the effective acceleration about the body's center:

$$a_{\mathrm{eff}^{\hat{\imath}}}(X) = a_0^{\hat{\imath}} + \mathcal{T}_{\hat{\jmath}}^{\hat{\imath}} X^{\hat{\jmath}} + O(|X|^2), \qquad \begin{cases} a_0^{\hat{\imath}} \neq 0, & \text{supported laboratory,} \\ a_0^{\hat{\imath}} = 0, & \text{freely falling laboratory.} \end{cases} \tag{45}$$

The nonzero constant term loads a supported laboratory through its boundary traction. Free fall removes that term. The remaining tidal term changes sign across the center, so it cannot be represented by one uniform scalar contraction.

For a bound body of local energy density $\varepsilon(X)$, the leading tidal force density must be balanced by an internal Standard-Model stress:

$$f_{\mathrm{tide}^{\hat{\imath}}}(X) = \frac{\varepsilon(X)}{c^2} \mathcal{T}_{\hat{\jmath}}^{\hat{\imath}} X^{\hat{\jmath}}, \qquad \partial_{\hat{\jmath}} \sigma^{\hat{\imath}\hat{\jmath}} + f_{\mathrm{tide}^{\hat{\imath}}} = 0, \qquad \int d^3X\, f_{\mathrm{tide}^{\hat{\imath}}} = 0. \tag{46}$$

The last equality holds when the origin is the center of energy. It explains how a tide can deform a body without accelerating its center away from free fall: the force monopole vanishes, but the opposing forces on different parts of the body do not. A freely falling dust cloud may change its internal separations, whereas a solid, molecule, atom, or other bound system develops stress because its Standard-Model binding resists that differential motion.

Once the binding problem determines the completed tidal stress, the same clock and ruler kernels used for every other load determine the measurable response:

$$\Delta T_{\mathrm{tide}^{\mu\nu}} \rightarrow \begin{pmatrix} \delta \ln \omega_a \\ \epsilon_{\hat{\imath}\hat{\jmath}} \end{pmatrix}_{\mathrm{tide}} = \begin{pmatrix} \mathcal{K}_{a,\mu\nu}^R \\ \mathcal{C}_{\hat{\imath}\hat{\jmath},\mu\nu}^R \end{pmatrix} * \Delta T_{\mathrm{tide}^{\mu\nu}}. \tag{47}$$

Equation (47) does not assign one universal tidal strain to every material. The response depends on the density profile, binding strength, construction, exposure time, resonances, and boundary conditions. It also prevents the tidal strain from being counted once through the completed tensor response and then added again as a separate mechanical correction.

This separation also identifies what a local release experiment can and cannot measure. For two otherwise identical devices evaluated at the same location after signal and relative-motion effects have been removed, the source-established ambient baseline is common and cancels. The released device approaches that local ambient reference, while the supported device retains only its additional construction-specific load response:

$$\begin{aligned} \varDelta_{\mathrm{drop-supp}} \ln\omega_a &\to -\delta\ln\omega_{a,\mathrm{supp}} + O(\chi_{\mathrm{tide}}, \epsilon_{\mathrm{tr}}, \delta_{\mathrm{hist}}), \\ \varDelta_{\mathrm{drop-supp}} \ln L_a(\hat{n}) &\to -\delta\ln L_{a,\mathrm{supp}}(\hat{n}) + O(\chi_{\mathrm{tide}}, \epsilon_{\mathrm{tr}}, \delta_{\mathrm{hist}}). \end{aligned} \tag{48}$$

Equation (48) is construction specific, and its sign becomes definite only after the support response of that clock or ruler has been calculated or calibrated. It does not predict a universal release jump equal to a complete source-to-reference comparison factor. On a branch where the additional support preparation slows the chosen clock and shortens the chosen ruler, the freely falling device differs from its supported counterpart by that residual amount before impact or capture applies a new load. The common local ambient baseline remains present in both states and is not counted again.

The accomplishment of this section is a controlled sequence. The epoch supplies the underlying matter baseline; a source establishes the local ambient response; stationary support adds a preparation; release removes that preparation through a causal Standard-Model transient; and a finite body retains the applicable ambient state, anisotropic tides, and any genuine irreversible history. Free fall is therefore unloading relative to the local ambient state, not a return to a universal vacuum and not the deletion of all source dependence.

8. Separation of Matter Response from Signal and Protocol Effects

Section 6 defined the intrinsic response of a physical clock or ruler to its prepared Standard-Model state. A remote observation adds other operations that must be kept distinct. First, the emitter's local state determines the frequency or length it physically produces. Second, the clock or ruler history determines any accumulated phase or stored record. Third, a signal transfers information between locations. Finally, the receiver applies a specified comparison protocol using its own local standards. These four contributions form one measurement; none is a second physical deformation of the matter.

The distinction matters because the Einstein-equivalent metric already summarizes the completed long-wavelength comparison. Once that representation has supplied the signal or common relativistic factor, the same factor cannot also be inserted as an additional local change of the emitter or receiver. Construction-specific shifts caused by temperature, pressure, loading, composition, or damage remain genuine local matter effects and are retained separately.

For a clock of construction a, the local state ρ_e fixes the rate at which its phase is produced:

$$\frac{d\phi_a}{d\tau_e} = \omega_a[\rho_e]. \tag{49}$$

The variable τ_e is the time counted locally by the emitter. Equation (49) concerns the clock mechanism itself. It says nothing yet about how rapidly the emitted cycles arrive somewhere else.

Signal transfer is described by the same phase viewed along its propagation path. If k_μ is the gradient of the signal phase and u_e^μ and u_r^μ are the emitter and receiver four-velocities, the two endpoints measure

$$\omega_{\mathrm{emit}} = -\left(u_e^\mu k_\mu\right)_e, \qquad \omega_{\mathrm{rec}} = -\left(u_r^\mu k_\mu\right)_r. \tag{50}$$

The contraction $u^{\mu}k_{\mu}$ converts one propagating phase into the frequency counted by a particular observer. The null-path description is the Einstein-equivalent infrared bookkeeping map; it does not assert that a geometrical medium is the microscopic carrier.

After an explicit reference state ρ_{ref} has been selected, define the intrinsic matter factor of clock a by $\mathcal{M}_a[\rho] \equiv \omega_a[\rho]/\omega_a[\rho_{ref}]$. For a coherent carrier in a calibrated propagation mode, the completed comparison is

$$\frac{\omega_{\text{rec}}}{\omega_a[\rho_r]} = \frac{\mathcal{M}_a[\rho_e]}{\mathcal{M}_a[\rho_r]}\,\mathcal{P}_{\text{sig}}, \qquad \mathcal{P}_{\text{sig}} \equiv \frac{(u_r \cdot k)_r}{(u_e \cdot k)_e}. \tag{51}$$

Equation (51) has a direct physical reading. The first ratio compares the two endpoint clock constructions in their actual local states. The second factor describes one calibrated signal transfer between them. Absorption, dispersion, or instrumental delay must either be negligible or included in that calibration. A source-established ambient comparison may be represented through the endpoint matter-standard ratio or through the Einstein-equivalent propagation map. Those are two representations of the same common contribution and must not be multiplied together. After that common contribution has been assigned once, $\mathcal{M}_a$ contains only construction-specific residual loading or state effects not already represented by $\mathcal{P}_{sig}$.

Collinear recession provides a familiar example. For constant relative speed v in flat propagation,

$$\mathcal{P}_{1\text{w}} = \sqrt{\frac{1-\beta}{1+\beta}}, \qquad \beta = \frac{v}{c}, \qquad \frac{\omega_{\text{return}}}{\omega_{\text{send}}} = \mathcal{P}_{1\text{w}}{}^2 = \frac{1-\beta}{1+\beta}. \tag{52}$$

The one-way factor gives the complete relativistic arrival-rate comparison for that protocol. A coherent reflection or calibrated transponder provides the round-trip relation shown in the same equation. Once the transfer has been calibrated, Equation (51) isolates any residual difference between the endpoint clock states without introducing another velocity factor.

Present clock rate and accumulated clock history are different observables. A clock carried along a physical state history $\mathcal{H}_a$ records

$$N_a = \frac{1}{2\pi}\int_{\mathcal{H}_a} \omega_a\,[\rho_a]\,d\tau_a, \qquad \Delta N = N_A - N_B. \tag{53}$$

The number N_a is the accumulated cycle count. Two clocks may be reunited at the same location, unloaded to the same local ambient state, and restored to the same present rate while retaining a nonzero ΔN, because their earlier histories were different. No continuing remote signal is required to read that stored phase difference.

Ruler measurements require the same separation between the object and the protocol. If $L_{\text{mat}}(\hat{n};\rho)$ is the ruler's intrinsic equilibrium length and $\mathcal{P}_L$ is the transfer factor defined by a particular measurement,

$$L_{\text{inf}} = \mathcal{P}_L[\text{protocol}, u_e, u_r, k, \hat{n}]\,L_{\text{mat}}(\hat{n};\rho). \tag{54}$$

A photograph, radar range, simultaneous endpoint assignment, and direct comoving comparison do not use the same $\mathcal{P}_L$. A local comparison has $\mathcal{P}_L = 1$; a radar measurement uses the receiver's clock and calibrated signal speed; an equal-time assignment compares two endpoint events selected by the chosen frame. The inferred length must therefore identify its protocol before it can be compared with the ruler's local material state.

The complete accounting can be summarized without assigning any effect twice:

$$\begin{aligned}&\text{prepared Standard-Model state}\\&\rightarrow \text{intrinsic clock or ruler response and accumulated phase}\\&\rightarrow \text{one calibrated signal transfer} \rightarrow \text{receiver protocol} \rightarrow \mathcal{O}_{\text{observed}}.\end{aligned} \tag{55}$$

This organization preserves the tested mathematics of frequency shift, radar distance, accumulated phase, and relativistic endpoint comparison. It also identifies the cleanest experimental controls. Co-located comparisons set the transfer factor to unity, coherent round trips calibrate the transfer independently, and reunited clocks compare accumulated histories after both instruments have returned to the same local state.

9. Force, Work, Inertia, and the Special-Relativistic Branch

The purpose of this section is to separate what physically happens while a force acts from what remains in a later relativistic comparison. The clean special-relativistic construction is first stated in free space, where the applicable ambient state is the current-epoch baseline. An external apparatus transfers energy and momentum to matter. Its local force distribution creates transient tensor stress, strain, heating, and clock response, while the total four-momentum determines the work required to reach a new velocity. After an ideal reversible acceleration ends and the body unloads, its local clocks and rulers return to that applicable ambient inertial state. The accumulated clock phase, momentum, and equal-time endpoint comparisons still retain the standard Lorentz relations because the completed histories differ.

The two descriptions are therefore complementary. The work-and-loading ledger describes the physical deviation while acceleration is transmitted. The phase-and-comparison ledger describes the relational result after the body has returned to its local ambient inertial state. Constant velocity is not treated as a continuing material load. Near a gravitating source, the same inertial calculation describes a further preparation relative to the source-established ambient baseline rather than replacing that baseline.

For the clean reversible branch, the body's invariant mass M_0 is unchanged. Standard-Model Poincare symmetry gives the energy-momentum relation

$$E^2 = p^2c^2 + M_0^2c^4. \tag{56}$$

Using the group velocity $\mathbf{v} = \partial E/\partial \mathbf{p}$, Equation (56) gives

$$E = \gamma M_0 c^2, \qquad \mathbf{p} = \gamma M_0 \mathbf{v}, \qquad \gamma = \frac{1}{\sqrt{1-v^2/c^2}}. \tag{57}$$

These quantities describe the complete body's energy and momentum relative to the original laboratory. They do not say that its invariant rest mass has become γM_0.

The energy must be supplied physically. Force changes momentum, power transfers energy, and integration gives the work accumulated from rest:

$$\mathbf{F} = \frac{d\mathbf{p}}{dt}, \qquad \frac{dE}{dt} = \mathbf{F}\cdot\mathbf{v}, \qquad W = \int \mathbf{F}\cdot d\mathbf{x} = (\gamma - 1)M_0c^2. \tag{58}$$

If the acceleration also leaves heat, excitation, radiation loss, or permanent deformation, those channels belong in the energy ledger and change the final invariant mass according to Equation (25). Equation (58) is the reversible result after those residual changes have been excluded.

The resistance to an additional velocity change is directional. Differentiating momentum gives

$$\mathcal{M}^{\text{in}}{}_{ij} \equiv \frac{\partial p_i}{\partial v_j} = \gamma M_0\left(\delta_{ij} + \gamma^2\frac{v_iv_j}{c^2}\right), \qquad M_{\parallel\text{in}} = \gamma^3 M_0, \qquad M_{\perp\text{in}} = \gamma M_0. \tag{59}$$

The longitudinal and transverse quantities are slopes of momentum with respect to an additional velocity change. They express the growing force required to keep accelerating; they are not three different rest masses.

For a finite longitudinal force,

$$v \to c \quad \Rightarrow \quad E, W, M_{\parallel \text{in}} \to \infty, \qquad a_{\parallel} = \frac{F_{\parallel}}{\gamma^3 M_0} \to 0. \tag{60}$$

The limiting speed is therefore approached only through unbounded accumulated work. This result follows from the Standard-Model energy-momentum relation before any clock or ruler comparison is made.

It is useful to normalize each work increment to the body's instantaneous energy. The accumulated coordinate and its reduced comparison factor are

$$d\Lambda_E \equiv \frac{dE}{E} = \frac{\mathbf{F}\cdot d\mathbf{x}}{E}, \qquad \Lambda_E(v) = \ln\frac{E}{E_0} = \ln\gamma, \qquad b_{\text{SR}} \equiv e^{-\Lambda_E} = \frac{1}{\gamma}. \tag{61}$$

The scalar b_{SR} is a completed comparison ratio, not a replacement for the tensor loading while the force acts. Its clock meaning follows from Standard-Model phase. Along a stable mass eigenstate,

$$d\varphi = \frac{1}{\hbar} p_\mu dx^\mu = -\frac{M_0 c^2}{\hbar}\, d\tau, \qquad \frac{d\tau}{dt} = \frac{M_0 c^2}{E} = \frac{1}{\gamma} = b_{\text{SR}}. \tag{62}$$

For two nearby internal energy levels transported along the same center trajectory, the difference of Equation (62) gives the familiar accumulated clock-phase ratio. This is a signal-free comparison between phases accumulated over different event histories. If a force is still acting and also shifts the intrinsic transition, that construction-specific shift is included once through the Section 6 clock kernel.

The corresponding ruler relation follows from the boost transformation of the endpoint events. For relaxed comoving separations $\Delta X_{\parallel}, \Delta X_{\perp}$,

$$\Delta X_{\parallel} = \gamma(\Delta x_{\parallel} - v\Delta t), \qquad \Delta X_{\perp} = \Delta x_{\perp}, \qquad \left.\frac{L_{\parallel}}{L_0}\right|_{\Delta t=0} = \frac{1}{\gamma}, \qquad \left.\frac{L_{\perp}}{L_0}\right|_{\Delta t=0} = 1. \tag{63}$$

The final two ratios use endpoint events chosen at equal time in the original laboratory. They are protocol-defined correlations, not a claim that the unloaded comoving ruler has acquired a permanent local deformation.

The distinction between loading and comparison can now be stated in one causal sequence:

$$\begin{aligned} \Delta T_L^{\mu\nu} \neq 0 \quad &\Rightarrow \quad \text{intrinsic clock and ruler response while force is transmitted,} \\ \Delta T_L^{\mu\nu} \to 0 \quad &\Rightarrow \quad \omega_{a,\text{local}} \to \omega_{a,amb}, \quad L_{\text{mat}}(\hat{n}) \to L_{amb}, \quad (E, \mathbf{p}) = (\gamma M_0 c^2, \gamma M_0 \mathbf{v}). \end{aligned} \tag{64}$$

Residual heat, damage, excitation, or radiation would remain in the final state and must be included separately. In Equation (64), $\omega_{a,amb}$ and L_{amb} are the local ambient standards applicable after the force has been removed. On the ideal branch, local standards return to those ambient values, while accumulated phase and equal-laboratory-time comparisons retain $b_{SR} = 1/\gamma$.

The accomplishment is the ordinary special-relativistic branch recovered from Standard-Model energy, momentum, work, phase, and boost covariance. Physical acceleration requires force, performs work, and loads the body while that force is transmitted. Inertial coasting after unloading requires no continuing local deformation relative to the applicable ambient state. In free space that state approaches the current-epoch baseline; near a source it is the source-modified local baseline. The same framework nevertheless retains Einstein's tested phase, momentum, limiting-speed, and ruler-comparison mathematics.

10. Standard-Model Irreversibility, Enthalpy, and Entropy Production

Sections 3 through 9 treated nested local states, mechanical loading, causal unloading, measurement protocol, and inertial comparison. Cosmology supplies the slower underlying evolution of the epoch baseline itself. Matter can be mechanically unloaded while its applicable equilibrium state changes through reactions, scattering, radiation, binding, phase conversion, and redistribution. The question is not whether total energy disappears, but how much of the conserved energy remains available to maintain the earlier scale-setting configuration of matter.

The late homogeneous state is represented as one continuous path through Standard-Model state space. Let $\lambda(t)$ denote its common scale coordinate and let $Y(t)$ collect the dimensionless information that distinguishes one state from another, including couplings, mass and binding ratios, thresholds, chemical fractions, occupations, correlations, and spectral shape. The density operator, completed static stiffness, and available scale-supporting energy are then

$$\begin{aligned} \rho_{\mathrm{SM}}(t) &= \rho_{\mathrm{SM}}[\lambda(t), Y(t)], \\ A_{2,E}(t) &= A_{2,E}[\rho_{\mathrm{SM}}(t)], \\ \mathcal{E}_{\mathrm{drive}}(t) &= \mathcal{E}_{\mathrm{drive}}[\rho_{\mathrm{SM}}(t)]. \end{aligned} \tag{65}$$

The density operator is the quantum ledger of state populations, coherences, and correlations. In Equations (65)-(70), $\rho_{\mathrm{epoch}}(t)$ denotes the homogeneous epoch state and $A_{2,E}\left[\rho_{\mathrm{epoch}}(t)\right]$ denotes its completed transverse-traceless stiffness. This is the baseline inherited by an otherwise isolated local system at that epoch. A source may establish a further ambient state, and support or drive may prepare another deviation, without altering the cosmological power ledger or counting any level twice. The quantity $E_{\mathrm{drive}}(t)$ is not the total energy of the universe; it is the energy or free-energy inventory still available to support the selected equilibrium scale. Equation (65) makes the state, rather than an independently expanding geometry, the object that evolves. On the declared common-scale branch, this scale-supporting inventory carries the same covariant energy weight as every other energy contribution.

An infinitesimal homogeneous change couples to the enthalpy density of that state:

$$\begin{aligned} \mathcal{O}_{\psi} \equiv \left(\frac{\partial \varepsilon}{\partial \lambda}\right)_{Y} &= 3(\varepsilon + p) = 3h, \\ h \equiv \varepsilon + p &= Ts + \textstyle\sum_a \mu_a\, n_a, \\ (\varepsilon + B) + (p - B) &= h. \end{aligned} \tag{66}$$

The energy density is ε, the pressure is p, and h is the enthalpy density. Its thermodynamic form contains temperature T, entropy density s, and the chemical-potential contributions $\mu_a n_a$. The last equality shows why a state-independent vacuum offset cannot drive this evolution: adding B to the energy density and subtracting the same B from the pressure leaves $\varepsilon + p$ unchanged. Actual composition changes, binding thresholds, and correlations remain physical because they change Y rather than adding a constant to every state.

The central rate law has a precise thermodynamic meaning within the homogeneous discharge ledger. P_{loss} is not lost total energy; it is the power by which irreversible processes destroy the availability or free-energy inventory capable of supporting the earlier scale-setting state. With the reference state and temperature specified and reversible work and transport accounted for in the full ledger, the availability identity is $P_{\text{loss}}(t) = T_{\text{ref}}(t)\dot{S}_{\text{prod}}(t)$, with $\dot{S}_{\text{prod}}(t) \geq 0$. In the fully local nonequilibrium description, the same power is the integral of the entropy-production density, including reaction, transport, binding, and correlation contributions. Total energy remains conserved while entropy production changes which part of it remains available:

$$\begin{aligned} P_{\text{loss}}(t) &\equiv -\dot{\mathcal{E}}_{\text{drive}}(t) = T_{\text{ref}}(t)\dot{S}_{\text{prod}}(t) \geq 0, \qquad \dot{E}_{\text{tot}} = 0, \\ \mathcal{H}_L(t) &\equiv -\frac{\dot{L}}{L} = \frac{P_{\text{loss}}}{\mathcal{E}_{\text{drive}}} = -\frac{1}{2}\frac{\dot{A}_{2,E}}{A_{2,E}}. \end{aligned} \tag{67}$$

Equation (67) follows by differentiating the exact common-scale relation: the driving energy and ruler length carry one power of the covariant scale, while the epoch stiffness carries two. Appendix C.3 makes this relation explicit in Equation (C12). Within the OQG discharge description, relaxation is entropic in nature, and the fractional rate is the entropy-production power divided by the remaining available inventory, rather than $\dot{S}_{\text{prod}}$ by itself. Covariance fixes the scale relation; the effective time constant is reconstructed from observations, and its microscopic origin remains to be calculated.

The familiar discharge of a capacitor provides the closest elementary analogy. A discharge variable X obeys a fractional decay law determined by an effective time constant. The OQG rate has the same mathematical architecture when its effective response time is defined by remaining availability divided by entropy-production power:

$$\tau_{\text{eff}}(t) \equiv \frac{\mathcal{E}_{\text{drive}}(t)}{P_{\text{loss}}(t)} = \frac{1}{\mathcal{H}_L(t)} = R_{\text{eff}}(t)C_{\text{eff}}(t), \qquad \frac{L(t)}{L(t_0)} = \exp\left[-\int_{t_0}^{t} \frac{dt'}{\tau_{\text{eff}}(t')}\right]. \tag{68}$$

The analogy does not assert that matter contains literal circuit components. It identifies the same structure: entropy-producing irreversibility plays the role of discharge, the remaining available state inventory plays the role of capacity, and their ratio fixes the fractional rate. OQG supplies an additional constitutive relation that sharpens this decomposition. On the homogeneous self-similar branch, $A_{2,E}[\rho_{\text{epoch}}(t)]$ carries two powers of the common Standard-Model spectral scale, while a charge-normalized capacity-like quantity carries the inverse first power. Its normalized canonical factor is therefore fixed by the already-derived stiffness:

$$\frac{\mathcal{C}_A}{\mathcal{C}_{A0}} = \left(\frac{A_{2,E,0}}{A_{2,E}}\right)^{1/2}$$

The canonical capacity factor is therefore not an additional cosmological fit function. Writing the effective response time as a product isolates the remaining dimensionless entropy-production and transport response:

$$\frac{\tau_{\text{eff}}}{\tau_0} = \frac{\mathcal{R}_A}{\mathcal{R}_{A0}}\frac{\mathcal{C}_A}{\mathcal{C}_{A0}}$$

The absolute normalization of the capacity-like quantity need not be known for a cross-epoch comparison; on the declared common-scale branch, its scale dependence is fixed by $A_{2,E}[\rho_{\text{epoch}}(t)]$. The residual dimensionless response contains the Standard-Model information associated with entropy production, occupations, binding, thresholds, transport, correlations, and departure from detailed balance.

Sections 11 and 12 show that the observed curvature is reconstructed as evolution of this entropy-production response after the canonical capacity scaling has been removed.

At the microscopic level, $\dot{S}_{\text{prod}}$ is generated by the completed real-time reaction, transport, and stress-correlation ledger [3, 4, 12, 13, 15, 17, 22]. Exact detailed balance gives $\dot{S}_{\text{prod}} = 0$ and therefore $P_{\text{loss}} = 0$. Away from balance, positive entropy production irreversibly depletes the availability of the earlier scale-supporting state, while the transverse-traceless projection determines how much of that redistribution changes $A_{2,E}[\rho_{\text{epoch}}(t)]$. The relaxation is entropic in nature within this OQG description; a completed microscopic calculation must supply the rate and its time dependence. If the normalized entropy-production-to-availability ratio were constant, the result would remain self-similar. The observed Dark-Energy-like curvature is $\mathcal{R}_{\text{ent}}(z)$, the measured departure of that normalized ratio from constancy. Technical Appendix C.3 states the conserving microscopic target and its limits.

To separate the obvious overall energy scale from the dimensionless state dependence, introduce a representative Standard-Model scale E_s and define the local state-response ratio $r_{\text{ent}}(Y)$ by

$$\mathcal{H}_L(t) = \frac{E_s(t)}{\hbar} r_{\text{ent}}[Y(t)], \qquad r_{\text{ent}}(Y) \equiv \frac{\hbar P_{\text{loss}}}{E_s \mathcal{E}_{\text{drive}}}. \tag{69}$$

The prefactor in Equation (69) supplies the natural inverse-time scale. Everything that depends on entropy production, composition, occupation, binding, thresholds, transport, correlations, and departure from detailed balance is contained in the dimensionless ratio. This quantity is not yet an observational fit; it is the microscopic Standard-Model object that a future low-energy calculation must determine.

Normalize that state-dependent part to the present state Y_0. The complete homogeneous rate history then separates into a leading scale ratio and a normalized response shape:

$$\frac{\mathcal{H}_L(t)}{\mathcal{H}_L(t_0)} = \frac{E_s(t)}{E_s(t_0)} \mathcal{R}_{\text{ent}}(t), \qquad \mathcal{R}_{\text{ent}}(t) \equiv \frac{r_{\text{ent}}[Y(t)]}{r_{\text{ent}}(Y_0)}, \qquad \mathcal{R}_{\text{ent}}(t_0) = 1. \tag{70}$$

Holding Y fixed gives the self-similar rate baseline. The common-scale identities remain exact on the declared covariant branch. Changes in dimensionless occupations, binding, transport, and correlations enter the residual response and its time dependence; their evolution is separate from the common covariant scaling weights. Sections 11 and 12 reconstruct the required effective-time history from redshift observables. Calculating the microscopic channels and coefficients that produce this history is a subsequent task, beyond the present observational test.

This section gives the OQG discharge description a local causal chain with a conserved energy ledger: Standard-Model reactions, scattering, transport, binding, and phase change produce entropy; positive entropy production destroys availability for preserving the earlier equilibrium; the completed transverse-traceless response converts that changing state into $A_{2,E}[\rho_{\text{epoch}}(t)]$; and the entropy-production-to-availability ratio fixes the contraction rate of matter standards. A constant vacuum offset cancels, total energy remains conserved, and no Dark Energy substance is introduced. The RC form in Equation (68) supplies a physically motivated family for the observational test, while the microscopic origin of the effective time constant remains a separate research calculation.

11. The Hubble Law from Cross-Epoch Matter Standards

Section 10 obtained a local rate at which irreversible Standard-Model redistribution changes the common matter scale. The present section shows how that local rate becomes redshift, the Hubble law, chronometer measurements, and distance observations. The physical starting point is not a substance that expands space. It is the comparison of an emitter's earlier clocks and rulers with the receiver's present clocks and rulers after signal propagation has been counted once.

The near-uniformity of the background Hubble rate follows naturally from this ordering. Matter governed by the same Standard Model and occupying the same coarse-grained epoch state has the same fractional evolution rate wherever it is located. The common background rate therefore follows from a common local law and does not require signal-mediated coordination among distant regions. A gravitating source establishes a local ambient response relative to that epoch baseline, and local motion, support loading, inhomogeneity, and measurement systematics produce further deviations. Cross-epoch observations must separate those nested local contributions, but the homogeneous background rate is uniform because the underlying epoch law is common.

This explains the Hubble law without requiring a Big Bang expansion event or an independently physical expansion of spacetime as its continuing cause. It does not erase the separate evidence that the early universe was hot and dense. In the OQG account, cooling supplies an essential operational boundary: as the hot, dense state passed through particle, nuclear, and binding thresholds, stable bound systems formed. Atomic transitions and equilibrium separations then became the durable clocks and rulers used by later observers. Cooling therefore established the operative matter standards and set the initial conditions for their subsequent evolution on the bound-state branch.

Let t_0 be the reception epoch. The inverse matter-standard scale inferred by the present observer is

$$\begin{aligned} \mathfrak{A}(t) &\equiv \frac{L(t_0)}{L(t)} = \frac{\omega_a(t_0)}{\omega_a(t)} = \sqrt{\frac{A_{2,E}(t_0)}{A_{2,E}(t)}} = \frac{\mathcal{E}_{\mathrm{drive}}(t_0)}{\mathcal{E}_{\mathrm{drive}}(t)}, \\ \mathfrak{A}(t_0) &= 1. \end{aligned} \tag{71}$$

Equation (71) compares the same specified ruler or clock construction at two points on the homogeneous state trajectory. Earlier standards are not assumed to coexist locally with present standards. Their comparison is carried to the observer by physical records and signals. The quantity $\mathfrak{A}$ is therefore an operational comparison scale, not an additional substance.

Its local logarithmic rate is

$$H_{\mathrm{op}}(t) \equiv \frac{\dot{\mathfrak{A}}}{\mathfrak{A}} = -\frac{\dot{L}}{L} = -\frac{\dot{\omega}_a}{\omega_a} = -\frac{1}{2}\frac{\dot{A}_{2,E}}{A_{2,E}} = \frac{P_{\mathrm{loss}}}{\mathcal{E}_{\mathrm{drive}}}, \qquad H_0 \equiv H_{\mathrm{op}}(t_0). \tag{72}$$

This is the operational Hubble rate. Every term in Equation (72) is local: the fractional evolution of a matter standard, the evolution of $A_{2,E}\left[\rho_{\mathrm{epoch}}(t)\right]$, or the Standard-Model entropy-production power divided by remaining availability. The equality does not require a galaxy's increasing geometrical separation to be the microscopic cause.

For scale, the datum $H_0 = 69\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$ corresponds to the extremely slow present contraction

$$-\dot{L}(t_0) = 7.06\ \mathrm{nm\,century^{-1}} \left(\frac{L(t_0)}{1\ \mathrm{m}}\right)\left(\frac{H_0}{69\ \mathrm{km\,s^{-1}\,Mpc^{-1}}}\right). \tag{73}$$

Neighboring standards co-evolve, so this drift is not exposed by placing two present-day rulers side by side. Cosmological measurements compare different epochs. Section 8 showed that endpoint motion, transition-specific response, propagation, and receiver protocol must each be assigned once. For homogeneous endpoints, stable dimensionless transition physics, and source-free electromagnetic propagation, those additional factors reduce to unity and the observed redshift becomes

$$1 + z = \frac{1}{\mathfrak{A}(t_e)} = \frac{L(t_e)}{L(t_0)} = \frac{\mathcal{E}_{\text{drive}}(t_e)}{\mathcal{E}_{\text{drive}}(t_0)} = \sqrt{\frac{A_{2,E}(t_e)}{A_{2,E}(t_0)}}. \tag{74}$$

The emitter at t_e and the receiver at t_0 occupy genuinely different matter states. The signal carries their phase comparison; it does not acquire a second geometrical redshift after the endpoint-state ratio in Equation (74) has already been included.

Differentiating that comparison produces the cosmic-chronometer identity, and its short-distance limit produces the ordinary Hubble law:

$$H_{\text{op}}(z) = -\frac{1}{1+z}\frac{dz}{dt_e}, \qquad c_0 z = H_0 D + O(D^2). \tag{75}$$

The label $c_0 z$ is the conventional recession-velocity shorthand. In the matter-first description, the homogeneous term measures the accumulated difference between earlier and present standards. Peculiar velocities and local loading remain separate corrections.

Once $H_{\text{op}}(z)$ has been obtained, the usual receiver-unit distances follow without changing their successful observational mathematics:

$$\begin{aligned} D_C^{[0]}(z) &= c_0 \int_0^z \frac{dz'}{H_{\text{op}}(z')}, \\ D_A(z) &= \frac{D_M(z)}{1+z}, \qquad D_L(z) = (1+z) D_M(z) = (1+z)^2 D_A(z). \end{aligned} \tag{76}$$

The first line is the radial distance inferred in the receiver's present units. The second line is distance duality for transparent propagation [9]. OQG changes the physical cause assigned to these relations, not the relations themselves.

If the dimensionless Standard-Model state Y is held fixed after coarse graining, Equation (70) gives the leading self-similar history

$$E_{\text{ss}}(z) \equiv \frac{H_{\text{op}}(z)}{H_0} = 1 + z, \qquad \mathcal{R}_{\text{ent}}(z) = 1. \tag{77}$$

Equation (77) is a parameter-free baseline, not a claim of perfect microscopic proportion. Local and rapidly varying departures may average away, whereas a slow coherent change in entropy-production power relative to remaining availability produces observable curvature. Figure 1 compares the baseline with 32 cosmic-chronometer measurements, the fitted RC response derived in Section 12, and a flat-ΛCDM reference fitted to the same chronometer data.

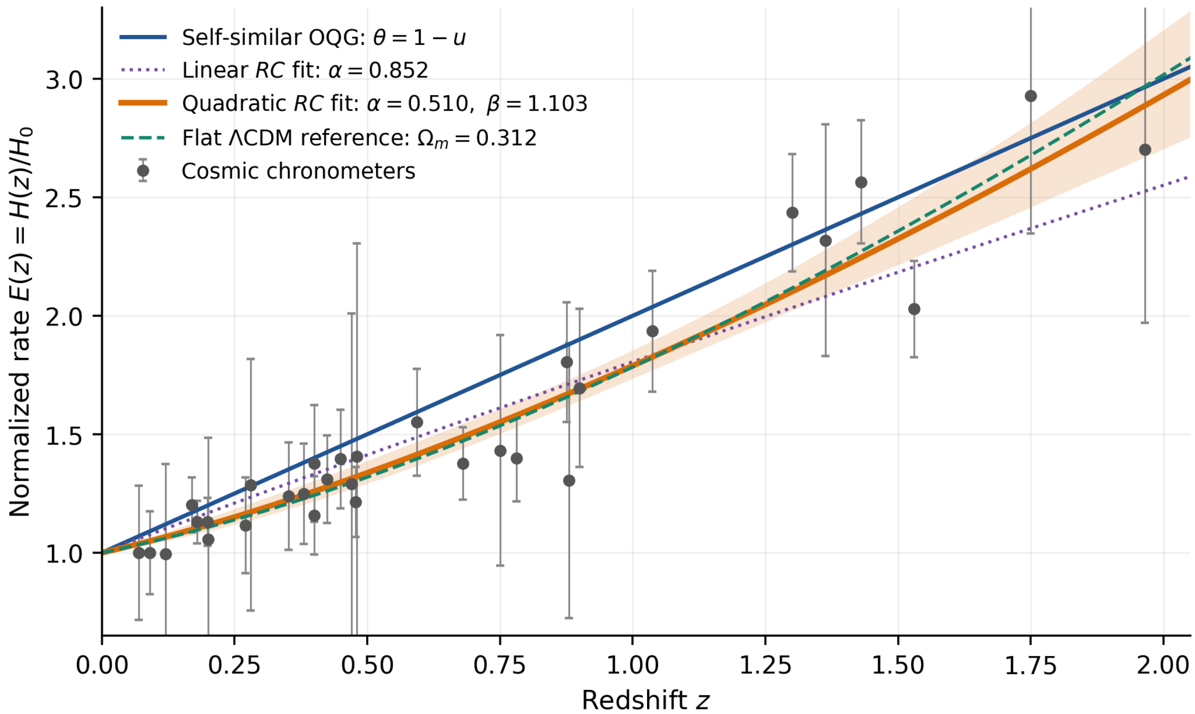

Fig. 1 Thirty-two cosmic-chronometer measurements of $E(z) = H(z)/H_0$ compared with the self-similar OQG baseline, the best one-parameter linear-RC law, the two-parameter quadratic-RC reconstruction with its correlated parameter band, and a flat-ΛCDM reference fitted to the same chronometers. The dimensional datum is $H_0 = 69\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$. Error bands and fit statistics use the displayed diagonal uncertainties and are not covariance-complete likelihoods [10]

The corresponding Alcock-Paczyński observable combines the instantaneous rate with its accumulated reciprocal:

$$F_{\mathrm{AP}}(z) \equiv \frac{D_M(z)}{D_H(z)} = E(z) \int_0^z \frac{dz\prime}{E(z\prime)}, \qquad F_{\mathrm{AP,ss}}(z) = (1+z)\ln(1+z). \tag{78}$$

Figure 2 applies Equation (78) to the six DESI DR2 measurements. The quadratic RC parameters are obtained only from the chronometers; no parameter is refitted to the DESI values.

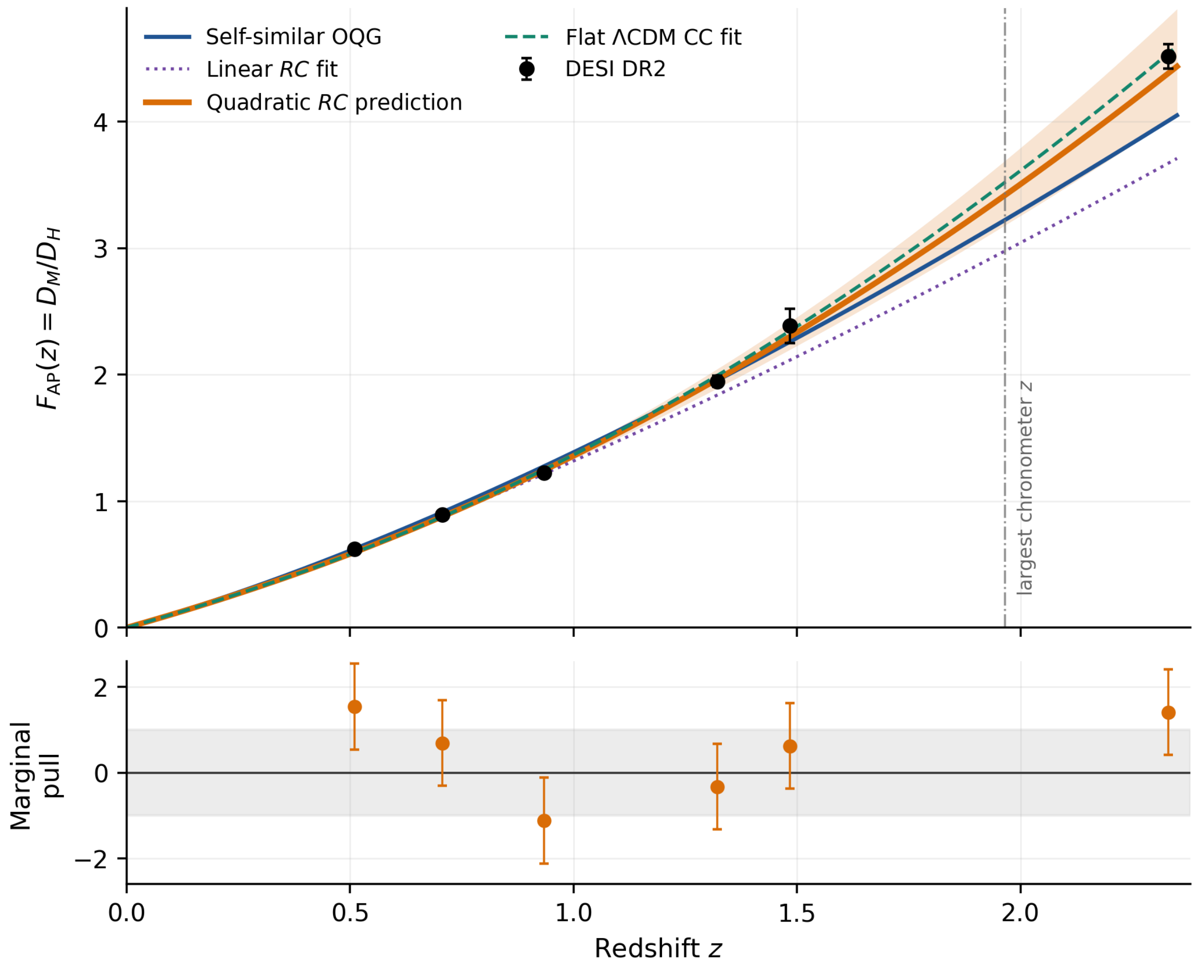

Fig. 2 DESI DR2 measurements of $F_{\mathrm{AP}} = D_M/D_H$ compared with the self-similar baseline, the chronometer-fitted linear-RC law, the chronometer-fitted quadratic-RC prediction with its correlated parameter band, and the chronometer-fitted flat-ΛCDM reference. The lower panel shows marginal residuals of the quadratic RC prediction. The vertical line marks the largest chronometer redshift; the Ly-α point is therefore a modest extrapolation of the chronometer fit. Because the RC family was formulated after inspection of the high-redshift behavior, this is a no-refit cross-dataset consistency test rather than a prospectively blind significance test [5]

Table 1. DESI DR2 no-refit comparison for the chronometer-fitted quadratic RC response.

Tracer	z	Measured F_{AP}	RC prediction	Marginal pull
LRG1	0.510	0.622 ± 0.017	0.596	+1.54
LRG2	0.706	0.892 ± 0.021	0.877	+0.69
LRG3+ELG1	0.934	1.223 ± 0.019	1.244	−1.12
ELG2	1.321	1.948 ± 0.045	1.963	−0.33
QSO	1.484	2.386 ± 0.136	2.301	+0.63
Ly-α	2.330	4.518 ± 0.097	4.381	+1.41

The conventional homogeneous map is recovered by identifying the inverse matter-ruler scale with an effective scale factor:

$$a_{\text{eff}}(t) \equiv \mathfrak{A}(t), \qquad a_{\text{eff}}(t_0) = 1, \qquad 1 + z = \frac{a_{\text{eff}}(t_0)}{a_{\text{eff}}(t_e)}, \qquad H_{\text{eff}} = \frac{\dot{a}_{\text{eff}}}{a_{\text{eff}}} = H_{\text{op}}. \tag{79}$$

Geometry therefore remains an exact infrared representation of the measurements. The change is causal and ontological: the right-hand-side Standard-Model state does the physics, while the geometrical scale factor records the inverse evolution of matter standards. The accomplishment of this section is to obtain the uniform Hubble background, redshift, chronometer relation, distances, and Alcock-Paczyński observable from one local matter law. Section 12 now asks whether the required departure from self-similarity has the time dependence of the discharge process identified in Section 10.

12. Apparent Acceleration as an RC Curvature of the Matter-Scale History

The Hubble rate is the first derivative of the matter-standard history. Apparent cosmic acceleration is its curvature. The objective of this section is not to introduce a new cosmological fluid, but to determine whether the departure from the self-similar OQG baseline has the form of the entropy-production and availability law derived in Section 10.

For the effective comparison scale, the conventional deceleration parameter is the kinematic identity

$$q_{\text{op}} \equiv -\frac{\mathfrak{A}\ddot{\mathfrak{A}}}{\dot{\mathfrak{A}}^2} = -1 - \frac{\dot{H}_{\text{op}}}{H_{\text{op}}{}^2}. \tag{80}$$

A negative q_{op} does not mean that the matter ruler expands. The ruler can continue to contract while its fractional contraction rate changes slowly enough that the inverse ruler scale has positive curvature.

Substituting the local rate law from Section 10 and the cross-epoch mapping from Section 11 gives

$$\begin{gathered} \mathcal{R}_{\text{ent}}(z) \equiv \frac{H_{\text{op}}(z)}{H_0(1+z)}, \qquad \mathcal{R}_{\text{ent}}(0) = 1, \\ E(z) = (1+z)\mathcal{R}_{\text{ent}}(z), \qquad q_{\text{op}}(z) = \frac{d\ln\mathcal{R}_{\text{ent}}}{d\ln(1+z)}. \end{gathered} \tag{81}$$

Thus the normalized response is the actual fractional contraction rate divided by the leading self-similar rate. In the conserved Standard-Model ledger of Section 10, it is the redshift-dependent entropy-production power divided by the remaining scale-supporting availability, after the canonical stiffness scaling has been removed. The stiffness relation separates that canonical capacity factor from the residual dimensionless entropy-production and transport response. Equations (72) and (74) imply the following cross-epoch scaling on the homogeneous comparison branch:

$$\frac{A_{2,E}(z)}{A_{2,E,0}} = (1+z)^2, \qquad \frac{\mathcal{C}_A(z)}{\mathcal{C}_{A0}} = \frac{1}{1+z}$$

The remaining factor is therefore determined directly by the reconstructed response:

$$\frac{\mathcal{R}_A(z)}{\mathcal{R}_{A0}} = (1+z)\theta(z) = \frac{1}{\mathcal{R}_{\text{ent}}(z)}$$

The parameter-free self-similar branch has a unit residual response. Apparent acceleration is then the logarithmic evolution of this residual Standard-Model entropy-production and availability response:

$$q(z) = -\frac{d\ln[\mathcal{R}_A(z)/\mathcal{R}_{A0}]}{d\ln(1+z)}$$

The remaining physical target is therefore narrower than a complete new cosmological fluid. The canonical capacity factor has already been fixed by $A_{2,E}\left[\rho_{\text{epoch}}(t)\right]$, while the observed curvature resides in $\mathcal{R}_{\rm ent}(z)$, the residual dimensionless evolution of projected entropy-production power relative to availability. The data reconstruct that response; the low-energy microscopic calculation must derive it.

The RC law is most naturally written in physical time. Define dimensionless lookback u, logarithmic redshift x, and normalized effective time constant θ by

$$u \equiv H_0(t_0 - t), \qquad x \equiv \ln(1+z), \qquad \theta(u) \equiv H_0 \tau_{\rm eff}(t). \tag{82}$$

Because $\tau_{\rm eff} = 1/H_{\rm op}$, the time-domain discharge and the redshift-domain observable obey

$$\frac{du}{dx} = \theta(u), \qquad E(z) = \frac{H_{\rm op}(z)}{H_0} = \frac{1}{\theta[u(z)]}, \qquad \mathcal{R}_{\rm ent}(z) = \frac{1}{(1+z)\theta[u(z)]}. \tag{83}$$

Equation (83) is the required bridge that an arbitrary redshift fit lacks. It preserves the physical order: choose the effective Standard-Model response time, integrate the matter-scale discharge, and only then calculate redshift observables.

The nested test begins with the lowest-order time dependences:

$$\theta_{\rm const}(u) = 1, \qquad \theta_{\rm lin}(u) = 1 - \alpha u, \qquad \theta_{\rm quad}(u) = 1 - \alpha u - \tfrac{1}{2}\beta u^2. \tag{84}$$

A literal constant RC gives $E(z) = 1$, the exact exponential-discharge limit. The linear law integrates exactly to $E(z) = (1+z)^\alpha$ and has constant $q_{\rm op} = \alpha - 1$. The parameter-free self-similar OQG baseline is already the special linear-RC case $\alpha = 1$, for which $\theta = 1 - u$ and $E = 1 + z$. This is the useful physical discovery: the baseline is itself a discharge law whose effective time constant shortens linearly into the past.

The best linear fit has $\alpha = 0.852 \pm 0.049$. The one-parameter linear member provides the leading empirical deformation of the self-similar baseline. The quadratic term adds the first change in slope and is therefore the lowest-order member able to represent a turnover in the reconstructed curvature. For Equation (84), it gives

$$q_{\rm op}(z) = -1 + \alpha + \beta u(z), \qquad u_{\rm turn} = \frac{1-\alpha}{\beta}, \qquad q_{\rm op}(z_{\rm turn}) = 0. \tag{85}$$

The two coefficients have direct meanings. The present slope of the effective time constant is set by α, while β measures how that slope changes into the past. Positive β allows slow present contraction to turn continuously toward faster earlier contraction.

Fitting only the 32 chronometer values with $H_0 = 69\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$ gives

$$\alpha = 0.510 \pm 0.186, \qquad \beta = 1.103 \pm 0.552, \qquad \mathrm{corr}(\alpha, \beta) = -0.962, \qquad \chi^{2\,\mathrm{CC,diag}} = 11.84 \quad (30\ \mathrm{dof}). \tag{86}$$

The strong anti-correlation is propagated rather than hidden. The fitted history has

$$q_0 = -0.490 \pm 0.186, \qquad z_{\rm turn} = 0.70^{+0.32}_{-0.14}, \qquad q_{\rm op}(2.33) = 0.346 \quad \text{at the best fit.} \tag{87}$$

The asymmetric turnover interval is the correlated 16th-to-84th-percentile range. Changing the fixed Hubble datum from 67 to 73 $\mathrm{km\,s^{-1}\,Mpc^{-1}}$ moves the best turnover only from $z = 0.67$ to 0.72, although the individual values of α and β change.

Figure 3 displays the same result in both observational and physical coordinates. The upper panel reconstructs the response ratio measured by chronometers. The lower panel shows the effective RC time constant itself. The fitted quadratic lies close to the self-similar line near the present, then bends toward a shorter response time at earlier epochs.

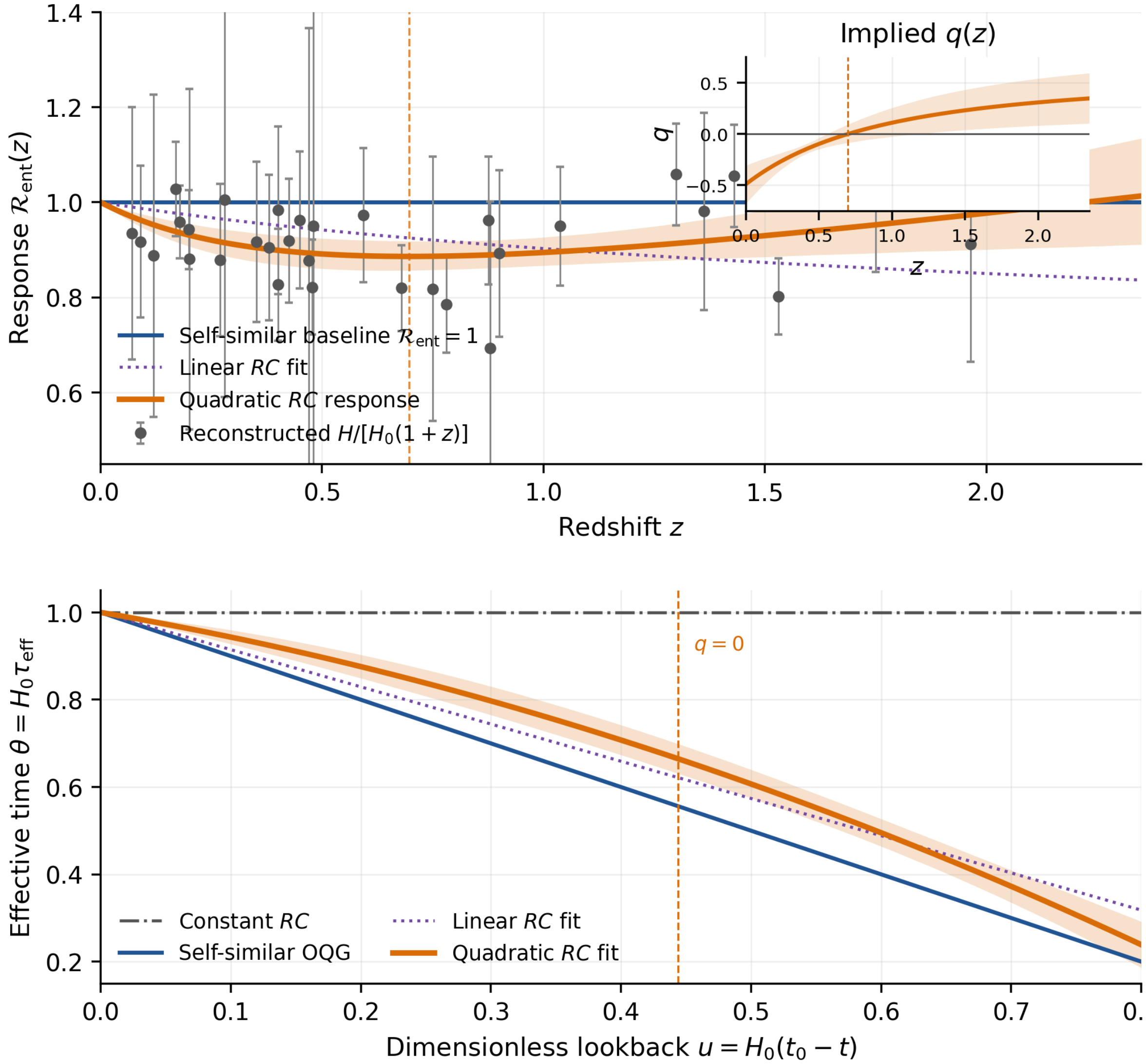

Fig. 3 Upper panel: the reconstructed $\mathcal{R}_{\mathrm{ent}}(z) = H/[H_0(1+z)]$, the self-similar baseline, the linear-RC fit, and the chronometer-fitted quadratic-RC response with its correlated parameter band. The inset gives the implied $q_{\mathrm{op}}(z)$. Lower panel: the normalized effective time $\theta = H_0\tau_{\mathrm{eff}}$ for constant RC, self-similar OQG, and the fitted linear and quadratic laws. The dashed line marks the best-fit $q_{\mathrm{op}} = 0$ crossing. The response curve is an observational reconstruction, not a first-principles Standard-Model calculation

The nested diagnostics identify the quadratic law as the lowest-order member that represents the observed turnover.

Table 2. Nested discharge-law diagnostics. All parameters are fitted to chronometers only.

Model	Shape parameters	Chronometer $\chi^{2_{\mathrm{diag}}}/\mathrm{dof}$	DESI $\chi^{2_{\mathrm{diag}}}$, no refit
Constant RC	0	$187.45/32$	1100.14
Self-similar OQG	0	$25.85/32$	37.27
Linear RC	1	$15.54/31$	88.19
Quadratic RC	2	$11.84/30$	6.60
Flat ΛCDM reference	1	$11.95/31$	6.55

The six DESI residuals of the quadratic RC curve are all below 1.55 marginal standard deviations, including the Ly-α point at 1.41. Its six-point diagonal statistic, 6.60, is nearly the same as the 6.55 obtained from the chronometer-fitted flat-ΛCDM reference. This does not make the two ontologies equivalent. It shows that the measured curvature can be represented by a smooth evolution of the matter response time without inserting a physical Dark Energy density or a nonzero cosmological integration constant.

The statistical interpretation is intentionally bounded. The constant and linear members provide nested controls, while the quadratic RC family was formulated after inspection of the high-redshift behavior. The DESI calculation is therefore a no-refit cross-dataset consistency check and a strong feasibility demonstration rather than a prospectively blind discovery significance [18, 21]. The diagnostics use displayed diagonal uncertainties; a covariance-complete likelihood and the microscopic calculation of $\tau_{\mathrm{eff}}(t)$ provide the next quantitative tests.

The earlier-time direction has a direct OQG interpretation. In the conventional geometrical description, inflation is a very rapid increase of the scale factor. Since the operational scale factor is the inverse matter standard,

$$a_{\mathrm{eff}} = \frac{L(t_0)}{L(t)}, \qquad \frac{\dot{a}_{\mathrm{eff}}}{a_{\mathrm{eff}}} = -\frac{\dot{L}}{L}. \tag{88}$$

In the matter-first account, primordial inflation would correspond to an extreme fast-contraction regime of the operative matter standard. The quadratic RC reconstruction points in that qualitative direction because its effective response time becomes shorter toward earlier epochs. It is nevertheless fitted only through $z = 2.33$ and must not be extrapolated through recombination or the primordial inflationary regime. The cooling and binding transitions identified in Section 11 are concrete Standard-Model candidates for establishing the later clocks, rulers, and response law; calculating those transitions is a separate microscopic program.

The accomplishment of this section is an observationally successful, physically motivated reconstruction of the lowest-order response capable of the measured turnover. A quadratic change in one effective response-time product, fitted only to chronometers, carries into all six DESI points without adjustment and performs comparably to the conventional flat-ΛCDM reference. The $A_{2,E}\left[\rho_{\text{epoch}}(t)\right]$ decomposition fixes the canonical availability scaling and identifies the reconstructed curvature with $\mathcal{R}_{\text{ent}}(z)$, the redshift evolution of projected Standard-Model entropy-production power relative to remaining availability. The homogeneous observations therefore determine Dark-Energy-like curvature in a matter-scale history without identifying a Dark Energy substance. OQG retains Einstein's comparison equations while selecting $\Lambda_{\text{int}} = 0$; a microscopic prediction of the effective time constant is a subsequent test of this interpretation.

13. Conclusions

This paper has organized OQG as a practical, educational framework built around one physical object: the completed Standard-Model response of a declared state. The full transverse-traceless kernel $\Pi^R_{TT}(\omega, k; \rho)$ contains the frequency and wave-number dependence. The coefficient $A_{2,E}[\rho]$ is its static long-wavelength stiffness where the stated static limit and gradient expansion exist. Writing the state argument is therefore not cosmetic; it identifies which matter-and-vacuum baseline supplies the clocks, rulers, inertia, loading response, and long-range compliance in the problem being solved.

The spectral fabric is the complete conservation-ready baseline behind that coefficient. It includes gauge and fermion fields, the Higgs sector, kinetic and binding energies, pressure and shear, boundaries and contact terms, occupations, correlations, thresholds, condensates, and measurable connected vacuum polarization and fluctuations. An arbitrary homogeneous additive vacuum-energy offset is not promoted into a connected local source, but the physical quantum vacuum remains present through every response that can change an observable.

The nested notation $A_{2,E}\left[\rho_{\text{epoch}}(t)\right]$, $A_{2,E}[\rho_{\text{ambient}}(x, t \mid S)]$, $A_{2,E}\left[\rho_{\text{prepared}}(x, t \mid S, B)\right]$, and $A_{2,E}[\rho_{\text{unloaded}}(\tau)]$ prevents a common conceptual error. Unloading removes an applied preparation relative to the applicable local ambient state; it does not erase the source, reset the body to a universal vacuum, or discard an irreversible history. Ratios between nested states compose, while independent force, signal, and protocol factors are assigned once.

For complete finite bodies, conserved four-momentum, the zero-momentum stress form factor, the balance of internal stresses, and the single ambient massless pole identify inertial, passive, and leading source mass. Proper loading then gives a matter-first equivalence principle: laboratories with the same applicable ambient state and the same complete tensor preparation have the same clock and ruler response. Causal release removes the support preparation, while finite tides remain as differential loading across an extended body.

Clocks and rulers are treated as specified Standard-Model constructions, not as abstract coordinates. Their responses depend on the chosen transition, binding potential, stress sensitivity, elastic compliance, orientation, temperature, and history. Signal propagation and receiver protocol are separate operations. The same accounting recovers special-relativistic energy, momentum, work, limiting speed, phase, and endpoint ruler comparisons while keeping constant velocity distinct from a continuing local material load.

Cosmology requires no change of physical ontology. The homogeneous epoch state $\rho_{\text{epoch}}(t)$ supplies the common evolving baseline, and $A_{2,E}[\rho_{\text{epoch}}(t)]$ supplies its stiffness. Standard-Model reactions, scattering, transport, binding, and phase change produce entropy. Positive entropy production destroys availability for maintaining an earlier scale-supporting configuration without destroying total energy. On the declared common covariant branch, the driving-energy ratio equals the square root of the $A_{2,E}[\rho_{\text{epoch}}(t)]$ ratio exactly. In this discharge description, the relaxation is entropic in nature, and the entropy-production power divided by remaining availability sets the contraction rate of matter standards.

This states the OQG interpretation of the apparent Dark Energy curvature explicitly. A constant normalized entropy-production-to-availability ratio gives the self-similar baseline. Its measured redshift dependence, $\mathcal{R}_{\text{ent}}(z)$, is the curvature reconstructed from chronometers and transferred without refitting to DESI. Entropy production supplies the irreversible mechanism in this description; the effective time constant is reconstructed from observations, while its microscopic channels and coefficients remain to be calculated. Dark Energy is not replaced by the word loss. It is replaced by a specific Standard-Model response that can be calculated and falsified.

With $H_0 = 69\ \text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$ as the dimensional datum, the two-parameter quadratic effective-time law fitted only to 32 cosmic chronometers gives $\alpha = 0.510 \pm 0.186$, $\beta = 1.103 \pm 0.552$, $\text{corr}(\alpha, \beta) = -0.962$, and $\chi^2 = 11.84$ for 30 degrees of freedom. Without refitting, the same response predicts all six DESI DR2 Alcock-Paczyński measurements with $\chi^2 = 6.60$, and every displayed marginal residual is below 1.6σ. This is a quantitative cross-dataset feasibility result for evolving matter standards on the $\Lambda_{\text{int}} = 0$ branch; it does not rely on a physical Dark Energy density.

The familiar composition percentages must then be stated carefully. Using the conventional Planck base-ΛCDM fit only as a benchmark, $\Omega_m = 0.315$, $h = 0.674$, $\Omega_b \simeq 0.049$, and the conventional complement is $\Omega_\Lambda \simeq 0.685$ [20]. On the OQG zero-Dark-Energy branch, that 68.5 percent is not transferred into matter; it is absent as a physical fluid. If the conventional nonrelativistic matter inventory is renormalized by itself, $f_b = \Omega_b/\Omega_m \simeq 15.6\%$ is ordinary baryonic matter—often loosely called visible matter, although not all baryons are luminous—and $f_{\text{non-baryonic}} \simeq 84.4\%$ is the conventional non-baryonic matter share. These are matter-sector composition fractions, not a new OQG critical-density budget and not yet an OQG solution of the dark-matter problem.

The subsequent microscopic target is specific: predict the effective time constant and residual response reconstructed from chronometers and DESI, using the relevant Standard-Model thermodynamics, transport, binding, occupations, and correlations. This is a separate research program; the present paper establishes the covariant scale relation and tests the quadratic effective-time history. Freezing that result before comparison would permit covariance-complete supernova, baryon-acoustic-oscillation, structure-growth, perturbation, and early-universe tests. The separate Black-Hole Onion project will apply the same state-dependent $A_{2,E}[\rho]$ framework to the finite-mass singularity problem without overloading the present educational manuscript.

Einstein's equations remain the successful infrared comparison structure. What changes is the physical system they represent. OQG begins with the Standard Model, keeps the complete response and every applicable baseline visible, and lets geometry summarize the long-wavelength comparison only after the matter calculation has been defined. Completing the microscopic entropy-production response would therefore do more than refine a cosmological fit: it would identify the physical origin of the measured curvature inside the same matter system that already supplies inertia, loading response, gravity, and the long-range tensor sector.

And what if this works? Do we return by default to an ontology in which physical space itself expands indefinitely; a unique globally conserved cosmological energy is generally unavailable; the homogeneous vacuum zero must be reconciled with gravitation; an additional Dark Energy component is invoked for the observed curvature; inertial, passive, and source mass remain separate empirical identifications; gravity and acceleration are related geometrically rather than traced to matched matter loading; black-hole singularities are accepted as endpoints of geometry rather than confronted with the finite response of matter; and a fundamental graviton is added even though the Standard-Model response already supplies the long-range two-helicity sector? OQG offers one matter-first physical system against which each of those additional assumptions can be tested. Matter tells matter how to scale. Geometry is just bookkeeping.

Declarations

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Competing Interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Author contributions. Todd J. Desiato conceived the OQG framework, developed the physical interpretation and research program, directed the theoretical synthesis, reviewed the derivations and literature, and approved the final manuscript.

Data availability. No new experimental datasets were generated for this theoretical study. The detailed derivations and proof layers are provided as Online Resource 1 (Technical Appendices A–C). The numerical reproducibility package, including Python code, benchmark inputs, and verification outputs, is provided as Online Resource 2 and available via Dropbox (v0.3 numerical reproducibility package). Empirical results discussed in the manuscript are taken from the cited literature.

Code availability. The Python source code and benchmark inputs required to reproduce the reported numerical checks are supplied as Online Resource 2 and available via Dropbox (v0.3 numerical reproducibility package). The package requires Python 3.11 or later and has no third-party Python dependencies.

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Use of generative artificial intelligence. The author used OpenAI ChatGPT, including GPT-5.5, GPT-5.6 Sol and GPT-6 Astra model configurations, as an AI-assisted research and writing tool for literature discovery, mathematical cross-checking, organization, drafting, and editing during development of the manuscript. The author reviewed the scientific arguments, equations, references, and final text and takes full responsibility for the content.

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