What the null cone fixes

Area, clock readings and the quantum state of a causal diamond

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Target: Venkatesa Chandrasekaran, *An algebraic quantization of gravity from the null cone*, arXiv:2611.34924v1 [hep-th], manuscript dated 23 November 2026 (L2–L7, L12).

Abstract

Chandrasekaran [1] defines a gravitational clock for a causal diamond along an incoming null generator: with the affine parameter set to zero at the past cap and its scale fixed by the gravitational boundary data there, its value at the corner gives the reading. At fixed corner area a sheared null cone takes a larger clock reading to reach the corner than a shear-free cone with the same initial area element and expansion (L1917–L1919). Fundamental Density Theory (FDT) returns the same focusing and the same one-loop backreaction at matched stress tensor, cosmological terms, initial and boundary data and gauge, with the same incoming coherent state, smearing and reduced measure at one loop. For a macroscopic causal diamond of given maximum size, the finite-dimension argument uses a chosen pure extension, the argument for a self-adjoint clock on the fixed-area space and strong evidence at finite Newton coupling and reduced Planck constant that the smoothed state converges in norm to the fixed-area Gaussian as the smoothing length tends to infinity. The corner weight is fixed by the area in units of the squared minimum stroke length. This identifies a ratio of areas, which in our reading counts no cells. The cone supplies the geometry; in an isolated cold-atom condensate, closed patterns keep time and record it with no external clock. Four prospective predictions concern the horizon flux of a prograde inspiral, the sign of the underlying difference in mean log distance residual between void and wall sightlines, the quotient of forward and reverse optical conversion rates, and the residual of a Loschmidt echo on that condensate. Each requires an input beyond the null-cone calculation.

1 Framework

The target is theoretical (`source_status`: theoretical). Reported results are the paper's constructions and calculations; measured and observed quantities are measurements. Derived relations, estimates, reconstructions and illustrative assumptions carry those meanings throughout. Physical loci L refer to Chandrasekaran [1]. Equation numbers refer to the same paper unless another source is named. Core clause numbers refer to the locked definitions and invariants [2]. FDT is a true extension of general relativity and quantum mechanics.

A clock, a length, a source

In 0.1 the omnium has energy E, mass m, electric and magnetic response coefficients ε_0, μ_0, and strand rate c. Write g for the spacetime metric, with components given in the chosen frame. A thread covers length d in duration t. The same state sets all four readings. For

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a confined mode of index q, $E_q, m_q, \omega_q, T_q, \ell_q$ denote energy, mass, angular frequency, period and thread length. Planck's constants are h and $\hbar = h/(2\pi)$, with π the circle constant. In SI, m and s denote metre and second. The exact conversion uses U-01 and U-03 [3].

$$\begin{aligned} E/m = c^2 = 1/(\varepsilon_0\mu_0) &= (d/t)^2, \\ E_q = m_q c^2 = \hbar\omega_q, \qquad & T_q = 2\pi/\omega_q = h/E_q, \\ \ell_q = cT_q = h/(m_q c), \qquad & d/t = c = 299792458\,\mathrm{m\,s^{-1}}. \end{aligned}$$

The Compton length is the distance the thread runs in a period. A boundary fixes its support independently. A closed pattern's strand runs at c on a helix: the translation square and the circulation square sum to the strand square (0.1d). Inertia includes the stress of closure. The translation share equals exterior compactness only for a held pattern. A photon is an unbound helical strand. Its energy rides the run; its helix has radius $\bar{\lambda} = \hbar c/E$, with shorter radius at higher energy. Unbinding sets the turning rate equal to the run and fixes the angle $\pi/4$. An open stroke keeps no time (I-2).

Newton's constant is G. Write P for pressure and B for the twist field. The force ceiling $F_{\max}$, Einstein coupling κ, minimum length $d_{\min}$, minimum duration $t_{\min}$ and Planck length ℓ_P obey 0.1a and 0.2:

$$F_{\max} = \frac{c^4}{4G}, \qquad \kappa = \frac{8\pi G}{c^4}, \qquad d_{\min}^2 = \frac{\hbar c}{F_{\max}} = 4\ell_P^2, \qquad t_{\min} = d_{\min}/c.$$

The square root of the stroke area gives the length floor. These intervals are one-sided infima. The medium's configurations are grainy; the floor imposes no lattice of intervals. The state adjusts globally. A cap specifies data on a bounded support, and the clock and ruler identifying a cut are themselves closed patterns of that medium (0.1a,b). The paper's quantization carries no matter: the cone supplies the geometry, and closed patterns supply the clock (Section 5).

Chart inventory and the force law

Write $\mathcal{M}$ for total gravitating energy in mass units. The field-point radius r_f, support radius R_b and source radius $R_s = 2G\mathcal{M}/c^2$ fix the evaluations in 0.3. The interior cutoff is r_c; its value does not enter this calculation (O-1). On A-1 the branch tag σ, exterior and interior ratios $\alpha_{\mathrm{ext}}, \alpha_{\mathrm{int}}$, and gap odds $X_{\mathrm{ext}}, X_{\mathrm{int}}$ specify the monopole atlas. The relation $\leq$ includes the cutoff itself. The branch-dependent coordinate is α_σ; the exponent in α_σ takes the exterior sign first:

$$\begin{aligned} \alpha_\sigma(r_f) &= (R_s/r_f)^\sigma, \qquad 0 < \alpha_\sigma(r_f) < 1, \\ \alpha_{\mathrm{ext}}(r_f) &= R_s/r_f, \quad X_{\mathrm{ext}} = R_s/(r_f - R_s), \quad R_s < r_f, \\ \alpha_{\mathrm{int}}(r_f) &= r_f/R_s, \quad X_{\mathrm{int}} = r_f/(R_s - r_f), \quad r_c \leq r_f < R_s. \end{aligned}$$

The exterior has $\sigma = +1$, the interior $\sigma = -1$. The ratio is bounded by its domain. The odds $X_\sigma = \alpha_\sigma/(1-\alpha_\sigma)$ carry only this algebraic meaning. The sign of the exponent selects the branch. The field point reads a field, a support evaluation reads a configuration, and the cross-centre evaluation of one source uses the separation to the other. On A-1 an odds enhancement by a factor $1 + x$, with $x \geq 0$, gives $\alpha_\sigma(1+x)/(1+\alpha_\sigma x)$ at the same declared evaluation (I-6).

Application	Coordinate	Warrant and use
A-1	$\alpha_\sigma(r_f)$	The two fixed lengths above. The fixed total mass over the volume at the field radius, divided by its value at the source radius, is $q_\sigma = \alpha_\sigma^{3\sigma}$; inside the source this comparison proxy increases inward, while the local density is densest at the skin.
A-2	$\beta_\sigma = \alpha_\sigma/(1+\alpha_\sigma)$	Geometric change of computational coordinate. Force, optics and density use their A-1 inputs.
A-3	α_{ovl}	Overlap contrast, open unit interval; no constructed odds here (O-2).
A-4	α_{conf}	Confinement position, open unit interval; no canonical odds here (O-3).
A-5	α_{mode}	Mode manifestation, open unit interval without a geometric assignment.
Skin	$\alpha_{\mathrm{core}} \to 1^-$	Schematic interior skin reading at the fold limit, with $r_f \to R_s^-$ on the spherical chart.

The applications without geometric warrant assign no numerical position to a mode. Neither the reciprocal branches of one atlas nor a gluing map between diamonds determines a bound configuration's separate interior chart, read with its skin at the fold and its skin radius taken from data (I-3).

For two nonoverlapping spherical supports let $\mathcal{M}_i$ be the mass of source i, $R_{\mathrm{s},i}$ its source radius and $R_{\mathrm{b},i}$ its support. At centre separation d_{sep} the exterior A-1 inputs $\alpha_i(d_{\mathrm{sep}})$ evaluate $r_f = d_{\mathrm{sep}}$ for each body. The corresponding masses are $\mathcal{M}_1, \mathcal{M}_2$. The two indexed ratios are $\alpha_1(d_{\mathrm{sep}}), \alpha_2(d_{\mathrm{sep}})$ for $R_{\mathrm{s},1}, R_{\mathrm{s},2}$. I-1 gives the universal force F; the numbered radii and ratios below evaluate the first and second source at the same separation; its monopole reduction on $R_{\mathrm{b},i} \geq R_{\mathrm{s},i}$ and $d_{\mathrm{sep}} \geq R_{\mathrm{b},1} + R_{\mathrm{b},2}$ is exact:

$$F = F_{\max}\alpha_1(d_{\mathrm{sep}})\alpha_2(d_{\mathrm{sep}}) = \frac{c^4}{4G}\frac{R_{\mathrm{s},1}}{d_{\mathrm{sep}}}\frac{R_{\mathrm{s},2}}{d_{\mathrm{sep}}} = \frac{G\mathcal{M}_1\mathcal{M}_2}{d_{\mathrm{sep}}^2}.$$

The open interval is universal, and inputs in it give a force below the ceiling. The pair domain further gives $F \leq F_{\max}/4$, with equality at contact of equal saturated supports. I-4 distinguishes this exact pair algebra from GR's leading weak-field, slow-motion force and from the source programme. No multipole or overlap remainder is used here (O-5).

What is solved before the radius is read

For metric $g_{\mu\nu}$, Einstein tensor $G_{\mu\nu}$ and stress tensor $T_{\mu\nu}$, the I-3 equation is $G_{\mu\nu} = \kappa T_{\mu\nu}$, with any prescribed cosmological contribution carried consistently in both descriptions. At the same source, cosmological input, initial and boundary data and gauge, the curvature agrees. The A-1 ratio is downstream of that solution. Bare Ω denotes a confinement domain. On a static spherical exterior let $\mathrm{d}\ell_{\mathrm{opt}}$ be optical distance and $\mathrm{d}\Omega^2$ the unit-sphere line element. At the field point r_f the optical face is

$$\mathrm{d}\ell_{\mathrm{opt}}^2 = \frac{\mathrm{d}r_f^2}{(1-\alpha_{\mathrm{ext}}(r_f))^2} + \frac{r_f^2\,\mathrm{d}\Omega^2}{1-\alpha_{\mathrm{ext}}(r_f)}.$$

Generalised Snell refraction is the Fermat jump law of this metric. The radial term is essential for the full leading bending angle. On this optical metric the Jacobi equation is the second variation of generalised Snell's law (I-3a). P-4 assigns the local causal aperture; its candidate constitutive index supplies no lensing index or timing shift here (O-8).

With rest contribution M, additional energy E_{add}, pressure P, volume V, temperature T, radiation constant a and Stefan–Boltzmann constant σ_{SB}, the mass ledger is 0.5 and I-7:

$$\mathcal{M} = M + E_{\mathrm{add}}/c^2 + PV/c^2 + aT^4V/c^2 + \cdots , \qquad a = 4\sigma_{\mathrm{SB}}/c.$$

Only disjoint channels enter. Radiation already in E_{add} is removed from that entry before writing its thermal contribution explicitly. Geometry accounts for binding. The quadratic gravitational source in the target's mean-field equation enters once by the same rule.

I-5 assigns matter modes to closed braids. The confinement operator D on domain Ω has mode u_q and angular eigenfrequency ω_q at fixed boundary data, strand count n, orientation χ and position on the inside/outside chart:

$$Du_q = \omega_q u_q.$$

Mass is a confinement eigenvalue. No form of the operator, its boundary data or its spectrum is written here (O-9). No inferred mode cost supplies a support radius. A change of occupancy of a radiative mode leaves the carrier identity intact. I-2 identifies photon, graviton, gluon, phonon and magnon as the same spin-one excitation in different regimes.

	Readings carried beside the core
CI-1	The graviton is the stroke in gravity's geometry, and the ripple is that geometry adjusting: its twofold turn is the rank of the tide read between neighbours … no linear sum of strokes carries it, pairs of the stroke's quanta do, and the composition is to be derived.
CI-2	identity is identity of the complete state (strand count and knot class, room, circulation, confinement mode), never of size; a link is never made between unmatched patterns.

Notation guard

The left column names the paper's letters in their original roles (NG-01 through NG-39). A letter in that column is a source label. The right column gives the notation used in the analysis.

Source	Paper's use	Manuscript use
$\alpha, \alpha_\eta, \alpha'$	Interval, basis and Lorentz indices, corner term and one-form, boost action, string scale.	Write indices and boost in words or use indexed Lorentz letters. Only the A-1 curvature ratio is read numerically here.
σ	JT coordinate, shear, Lorentz index.	Write shear ς_{AB}; reserve σ for the branch.
κ	Null inaffinity.	Use the word inaffinity; κ is the Einstein coupling.
γ	Worldline or relative boost.	Write worldline in words, Γ_{rel} for relative boost; γ is the Lorentz factor.
ϕ, φ	JT scalar, canonical variables, wavefunctions, state.	Name these in words; ϕ is the helical phase.
Ω	Symplectic form, incoming Gaussian.	Use $\mathfrak{W}, \mathfrak{G}_A$ respectively; Ω is a confinement domain.
n	Null normal, occupation, replica, JT family index.	Use $n^a, \mathfrak{n}, n_{\mathrm{rep}}$; name the JT index in words. Bare n counts strands.
R	Curvatures, curvature radius, right side.	Use $R_{ab}, R_{abcd}, R[q], R_{\mathrm{curv}}$ and a side subscript; core radii carry qualifiers.
X	Embedding, algebra element.	Name embedding in words; use $\mathcal{X}$ for an insertion. X denotes odds.
D	Diamond, displacement.	Use $\mathcal{D}$ for the region; name displacements in words. D is the confinement operator.

Source	Paper's use	Manuscript use
B	Area two-form, bounded-operator algebra.	Use $\mathfrak{B}^{\mu\nu}$; name the algebra in words. B denotes twist.
a	Index, annihilator, area fraction, angular radius integral, preparations and insertions.	Use an abstract index, a_k, words for the fraction, $\hat{a}_\varrho$ for the integral and words for preparations. Bare a is the radiation constant.
T	Torsion constraint, generic tensor.	Use $\mathfrak{T}$; T denotes temperature.
W	JT density operator, Wigner function.	Use $\mathcal{W}$ for the operator and name the Wigner function in words.
S	Corner, source operator, simplicity tensor, entropy.	Keep S for the corner; name the operators and constraint; use S_{vN} for entropy. Write three-sphere in words.
L	AdS radius, function space, side, overlap map, mode set, inverse multiplier.	Use L_{AdS}, a side subscript, $\mathcal{L}_{ij}$, and $\mathfrak{l}$ for the smoothing length. Name the space and set.
v	Radius ratio along a generator.	Use v_ϱ; bare v is translation or the speed of the gravitational flow.
ϵ, ϵ_0	Cap ratio, reference area form.	Use $\epsilon_c, \mathrm{d}\Omega_0$; ε_0 is the medium response.
μ	Cut area two-form.	Write $\mathrm{d}A$; μ_0 is the magnetic response.
A	Total corner area.	Use A_S; $\mathcal{A}$ is a wing record.

Source	Paper's use	Manuscript use
K, K_{AB}	Boost charge or aspect, second fundamental form.	Use $\mathcal{K}, \mathcal{K}(y), \mathbb{K}_{AB}$; the pair kernel has indices.
F	Curvature two-form, JT phase primitive, deformation.	Use $\mathcal{R}^{\mu\nu}$, $\mathcal{F}(u_*)$ and words for the deformation. F is force.
Φ	Dilaton, simplicity multiplier.	Use Φ_{JT} and name the multiplier in words.
N	Slicing lapse.	Use $\mathcal{N}$; N denotes the radial mode cutoff.
q	Limiting ratio of mean to maximum clock.	Use q_ℓ; q_σ orders the enclosed-mean density, a comparison proxy inside the source.
ρ_D, β, β_R	Density operator, inverse thermal scales.	Use $\hat{\rho}_{\mathcal{D}}, \beta_T$; ρ denotes density and β_σ is the A-2 coordinate.
G_N, M, r_h, G	Newton coupling, mass or cobordism, horizon radius, deformation, Gram matrix and correlators.	Use $G, \mathcal{M}, \mathfrak{M}, R_s$ on round Schwarzschild corners. Name the other objects in words.
$\ell^a, \ell(D)$	Null normal, maximum reading.	Keep ℓ^a, use $u_{\max}$ for the upper reading; ℓ_P is the Planck length.
ω	Extension state, frequency, spin connection.	Use ω_G for the state. Keep frequency ω and indexed connection $\omega^{\mu\nu}$.
λ	JT proper distance and cap distance, displacement smearing.	Name distances in words, cap at $\epsilon_c w/2$ for interval width w; omit the smearing parameter.

Source	Paper's use	Manuscript use
τ	JT global time, worldsheet time, observer proper time.	Keep τ for physical proper time or the stroke duration.
χ	Dressing displacement, wavefunctions, boundary phase.	Use $\mathfrak{d}^a$ for the displacement, words for the others; χ is orientation.
ξ	JT state label, cut displacement and charge.	Name these in words; ξ_{nq} is a confinement eigenvalue parameter.
ζ	Functions of the generator parameter and of a closed preparation.	Name the functions in words. The core's velocity-sphere coordinates have indices.
θ	Symplectic potentials, angular separation.	Name potentials and separation in words; θ denotes an optical angle.
η	Boost rapidity, internal metric and null volume form.	Keep η and $\eta_{\mu\nu}$, name the volume form in words.
u	Affine parameter.	Keep u for the generator and write the circulation speed in words.
s	Dimensionless area, its upper bound, band centre and eigenvalues.	Keep s, s_*, s_b, s_i in those roles; write the stroke length in words.
Λ	Bounded boundary-energy window.	Use Λ_E for the window and Λ for the paper's cosmological constant.

2 System chart

In the diamond $\mathcal{D}$, the incoming and outgoing null sheets H_p, H_q run between the spacelike caps Σ_0, Σ_1 and their common cut S (L686, L688). The affine coordinate u has its scale fixed by the tangent vector in a local Lorentz frame at its own cap. The local reading u_* and its

angular average $\bar{u}_*$ have length units. The cut metric q_{AB} has area radius ϱ, conformal metric $\bar{q}_{AB}$ and solid-angle form $\mathrm{d}\Omega_0$. Write ∂_u for the affine derivative. The radius at the corner is $\varrho_S(y)$ for generator label y. Choosing the affine origin at the cap and $\partial_u \varrho$ equal to unity there makes the clock reading u_* the corner value of u (L3064–L3065). The conformal metric has unit determinant relative to the fixed area form, and the radius is evaluated at the corner of each generator. On the chosen representation, projection onto clock readings at most $u_{\max}$ selects the Hilbert space of the diamond (L877, L883, L971, L2280).

Region	Fixed for the comparison	Returned by the solution
Expanding sheet	Initial radius, radial slope, conformal metric as a function along each generator	Area element, shear delay and clock at S, Eq. (3.25) through Eq. (3.28).
Corner	Match the induced metrics and identify angular labels	Relative frame boost and its conjugate area; common boost charge vanishes, Eq. (3.64).
Quantum diamond	Pure extension ω_G, cap normalization, maximum reading	Projected space $H_{\mathcal{D}}$ with dimension $d_{\mathcal{D}}$, using the self-adjoint clock argument and the finite-coupling norm estimate, Eq. (5.19), Eq. (5.39).
Round exterior	Total mass, exterior A-1 field point $r_f = \varrho > R_s$	Radius-gradient norm, tending to zero at marginality, Eq. (5.52a).
Inward sheet	Spherical limiting corner, fractional cap and intrinsic data	$v_\varrho = \varrho/\varrho_S$ and the inward clock, Eq. (5.52b).

The cap fraction ϵ_c is positive and strictly below unity (L895). A_S integrates $\varrho^2 \mathrm{d}\Omega_0$ at the corner. On a distorted cut the mean clock weights each generator by $\varrho_S \mathrm{d}\Omega_0$; it does not evaluate the clock at an average radius (L1019, L1024). An interior density measurement would require its own observed support and profile-weighted mean. The cut-area average reconstructs no local constitutive density profile (0.6, O-4).

3 Observation map

The truncated cone. The null cones extend from their respective caps and intersect at the corner (L688). In P-4 the truncated density cone at a point is the local light cone. In our reading the caps are the truncation. The two ends of the interval in 0.3a are core circles; the minimum stroke bounds the physical descent. Another diamond can cover the excised region. A process localized near the vertex then contributes to the amplitude for this second causal diamond and hence to the amplitude for the full region when physical states on the cap are summed as in Eq. (4.29) (L221–L223). In our reading a generic joint of two null sheets has no identification with the fold of one bound configuration. This cluster is a reading under P-4, 0.3a and 0.1a and corroborates no invariant (Use item 2). The P-4 identity of the truncated density cone with the local light cone is exact at each point. A resolved physical stroke shorter than the minimum length at fixed $G, \hbar, c$ would contradict the floor.

Containment. The paper varies the spin connection independently in the first-order action, subject to the simplicity constraint on the two-form (L650, L660). At fixed orientation with an invertible tetrad, the paper chooses the solution (3.4); with this choice the equations (3.5)

imply a torsion-free connection and $R_{ab} = \Lambda g_{ab}$ (L746, L749, L754–L758). In our reading the two-form $\mathfrak{B}^{\mu\nu}$ is an oriented area. In our reading this oriented area is the bivector grade of the strand plane of 0.1d, where c^2 is the strand spinor's area factor and rest energy is that grade. On the constraints, stationarity imposes the field equations; at leading order the classical trajectory with the incoming coherent state's smooth boundary data determines a solution of the nonlinear Einstein equations, Eq. (6.4). For an incoming coherent state the connected two-point function of the dressed metric through first order in Planck's constant determines the correction to the classical metric: the Einstein operator on the mean metric plus the expectation of its quadratic fluctuation term is of order $\hbar^2$, Eq. (6.9b), Eq. (6.13) (L3481, L3525, L3579, L3604). The paper notes that a graviton fluctuation with vanishing expectation value can still source the metric through the quadratic term in the Einstein tensor (L3543–L3544). I-7 counts radiation once in the total gravitating energy. Here the quadratic source is already in the solution. This cluster is a reading under I-3 and 0.1d and corroborates no invariant (Use item 2). With the reduced measure and the same boundary conditions the one-loop generating functional agrees with that of constrained general relativity; for coherent incoming data its source derivatives yield the graviton two-point function that drives the backreaction, differentiated at separated points before taking the second point to the first, with smearing held fixed (L3609, L3623–L3626). Different curvatures in FDT and general relativity at the same stress tensor, cosmological terms, initial and boundary data and gauge would contradict containment.

The tide and the focusing law. The screen tensors $\mathbb{K}_{AB}$ and ς_{AB} are respectively the null second fundamental form and its trace-free part. Raising the indices on ς uses the screen metric. The null second fundamental form $\mathbb{K}_{AB}$ has trace $\Theta_{(\ell)}$, the expansion along ℓ^a. The antisymmetric part of that form vanishes by Eq. (3.21) for the generators of the sheet, since ℓ^a is normal to the cut, by the torsionless condition (L911, L918, L920). In I-3a the trace projection of relative acceleration reads density and the trace-free projection reads the tide. The expansion itself measures change of area; it can be positive where the null Ricci trace vanishes. In a local matter rest frame the density term in null focusing has scale $8\pi G\rho/c^2$ for mass density ρ and the corresponding null normalization. For an affinely parametrized null generator in a solution of the vacuum field equations, $R_{ab}\ell^a\ell^b = 0$ (L932). Writing the expansion and shear in terms of the conformal metric and area radius puts the Raychaudhuri equation in the form (3.25c,e,f) (L943, L949, L955), in our reading the trace of the generators' Jacobi equation:

$$\Theta_{(\ell)} = 2\,\partial_u \varrho/\varrho, \qquad \partial_u \Theta_{(\ell)} = -\Theta_{(\ell)}^2/2 - \varsigma_{AB}\varsigma^{AB}, \qquad \partial_u^2 \varrho = -\varrho\,\varsigma_{AB}\varsigma^{AB}/2.$$

Thus outside the source shear alone decelerates the radial growth. On the incoming null cone the paper is free to specify the two polarizations of gravitational radiation through the conformal metric of its cuts; as radiation shears neighbouring null generators, their transverse separations grow at different rates in different directions (L620, L867). Where the spacetime itself remains smooth, the paper can place a spacelike cap before the null generators focus and choose a second causal diamond whose null boundaries are regular near a caustic of the generators (L629, L1034). In P-4 refraction, lensing and horizon formation are one phenomenon. In our reading this caustic is lensing. This cluster is a reading under I-3a and corroborates no invariant (Use item 2). The trace relation is exact before crossing for affine, twist-free

generators. A shear-dependent radial acceleration of the opposite sign at the same null Ricci contraction would contradict it.

The clock. The paper fixes the tangent vector in a local Lorentz frame at the past cap to set the affine scale; choosing the affine parameter to vanish there makes its corner value the clock reading (SA-15, L241–L244). In 0.1d the strand rate converts the omnium's time reading into its space reading; in our reading dividing the affine run in metres by c gives its duration on a closed clock in that calibration. Let p_{ϵ_c} be the initial radial slope and Ξ the integrated nonnegative shear in Eq. (3.26c). On the expanding patch $v_\varrho = \varrho/\varrho_S$ increases from cap to corner. The clock is p_{ϵ_c} times the difference of affine coordinates between cap and corner, so rescaling that coordinate by a positive factor leaves the reading invariant. The slope decreases by an exponential, while the elapsed interval at a fixed radius increases (L971, L972, L976, L987, L989, L992):

$$\partial_u \varrho = p_{\epsilon_c} e^{-\Xi(v_\varrho)}, \qquad u_* = \varrho_S \int_{\epsilon_c}^{1} e^{\Xi(v_\varrho)}\, \mathrm{d}v_\varrho.$$

Shear upstream therefore affects readings downstream even after the shear has ceased. With the initial area element and expansion held fixed, the sheared generator reaches the same corner area element later than the shear-free one (L1912–L1913). In our reading this delay is the cone's own lensing read through the area element (I-3a, P-4). The round, shear-free result is $u_* = (1-\epsilon_c)\varrho_S$. Angular averaging gives $\bar{u}_* \geq (1-\epsilon_c)\sqrt{A_S/(4\pi)}$ by Cauchy–Schwarz (L1041). For the illustrative radius profile of U-10, unity plus 0.3 times the cosine of polar angle plus 0.1 times the cosine of twice that angle, the cap fraction is 0.1 (U-11). With lengths in units of the profile scale and zero shear, the average is 0.9012 reference lengths and the lower bound is 0.8855. Those lengths differ because the angular weights differ. The slicing lapse $\mathcal{N}$ in Eq. (3.55) at fixed corner normalization depends on the shear between the cut and the corner through the same integral that enters the clock (L1350–L1351). The clock factor $\mathfrak{m}$ of 0.1c rescales the pattern's own length and time together and preserves its null cone. The P-4 aperture enters no clock number here (O-8). This cluster is a reading under I-2, 0.1c and 0.1d and corroborates no invariant (Use item 2). The clock reading u_* is independent of positive affine rescaling on a capped null cone. A smaller reading for a sheared cone than for a shear-free cone at fixed corner area and the same initial area element and expansion would reverse the derived ordering.

Relational geometry and the corner. The paper uses the edge modes to dress bulk observables, specifying both the event and the frame in which tensor components are measured (L1417); a simultaneous diffeomorphism of fields and embedding preserves the pullback (L1139). In 0.1a,b clocks and rulers are closed patterns of the omnium; their adjustment is the geometry. Equations (3.30)–(3.31) match tetrads and torsion-free connections of one solution in an overlap (L1085, L1089, L1093). In our reading the overlap maps are frame maps between diamonds of one solution and do not connect the two charts of a bound configuration. The normal-frame squeeze in Eq. (3.61) multiplies one null leg by the inverse of the other's factor (L1480). It preserves their normalization and the corner area. In 0.1d uniform motion squeezes the two factors of the interval quadrature and the area stays fixed. The surface charge $\mathcal{K}$ generating the relative boost follows from Eq. (3.43), with units of action

restored:

$$\mathcal{K} = \frac{A_S c^3}{8\pi G} = \frac{F_{\max} A_S}{2\pi c}.$$

The common boost carries zero charge after matching the induced metrics (L1225, L1228, L1508, L1512). On solutions of the gravitational constraints the Hamiltonian reduces to a surface charge (L138). Binding is already in the geometry and enters no separate channel in the mass ledger (0.5). This cluster is a reading under 0.1a,b,d and 0.2 and corroborates no invariant (Use item 2). The charge conversion is an identity; a nonzero common-boost charge for independently matched corner metrics would contradict the gluing law.

The quantum face. At fixed total area a state on the incoming null cone can fluctuate in both graviton polarizations and in the distribution of area over the corner. At fixed area, to calculate overlaps between such preparations at finite Newton coupling, the paper chooses a Gaussian wavefunction for the independent canonical pairs; its expectation values determine the inner product on the Fock space of graviton and edge-mode excitations (L1684–L1689). The midpoint prescription for the reduced Hamiltonian implements Weyl ordering; derivatives of the displacement operators at zero along smooth smearings yield symmetrized products of the corresponding field operators on their common domain in the fixed-area space (L1655, L1928–L1931). For radial mode k, the annihilation operator a_k of Eq. (4.9) combines its centered coordinate with its centered conjugate momentum in quadrature (L1724–L1730). In I-4 the wavefunction is the projection of a helix onto the plane normal to the cone axis. Write ψ for the helix projection, $\mathfrak{A}$ for its amplitude, ϕ_0 for the initial phase and ϕ_h for the turning phase at frequency ω. With orthonormal vectors $\mathbf{e}_1, \mathbf{e}_2$ normal to the run, their product is the unit bivector $\mathbf{B}$ of that plane:

$$\phi_h(t) = \phi_0 - \omega t, \qquad \mathbf{B} = \mathbf{e}_1\mathbf{e}_2, \qquad \psi = \mathfrak{A}e^{\mathbf{B}\phi_h}.$$

Here $\mathbf{B}^2 = -1$ and the rotor carries the single cylindrical phase angle, distinct from the half-angle spinor rotor. In our reading under I-4, a_k of Eq. (4.9) is that plane's coordinate, and the imaginary unit multiplying its momentum quadrature is the unit bivector $\mathbf{B}$. The exponent is dimensionless. The phase at observation is unknown; the strand class stays fixed. In any Gelfand–Naimark–Segal representation, Eq. (4.19) gives the Born probability of an outcome represented by an operator between zero and the identity for the normalized incoming state (L1882, L1889). The Gaussian Wigner function is positive and normalized; at zeroth order in $\hbar$ the Weyl product is ordinary multiplication. Equation (5.9) averages the fraction removed at each classical clock reading against the incoming Gaussian state's Wigner function at that order (L2357–L2359, L2365). In our reading under I-4 that Wigner average is ignorance of the helical phase at observation. The JT family in Eq. (2.14) shares a normalized smooth clock wavefunction as its envelope, with the matter field in the same normalized state; its members differ by an integer phase winding, and measuring the generator of dilations of the clock reading can distinguish them (L512, L517, L520, L524). With a source coupled to the radiation at the same value of the affine parameter along a null geodesic from S, when two such sources act on opposite sides of a cap, gluing fixes the ordering of their insertions because the later source acts on the state prepared by the earlier one (L1546–L1549); events do not commute (0.1a). This cluster is a reading under I-4 and corroborates no invariant (Use item 2). The Wigner-clock statement is at leading order in $\hbar$; the Born frequencies use the state's

own inner product. A resolved change of those frequencies for identical preparations and clamp settings would break the convergence.

The floor and the pair sum. Write Li_2 for the dilogarithm and Δq_k for a mode width. For a corner of fixed area write s for the dimensionless area, Δq_k for the rms width of its dimensionless radial coordinate, and $\mathcal{P}(s)$ for the connected overlap of the two quadratic insertions. In (4.32)–(4.34) the paper fixes the corner area and selects one polarization and one real-valued angular harmonic of the incoming Gaussian state, the mode index runs over positive integers, and the paper chooses the relative phase at annihilation by rotating the modes with a boundary unitary (L2150, L2165–L2166, L2169, L2172, L2177). The upper limit ∞ denotes all positive radial modes. Using the imaginary unit i, the area conversion of 0.1a and the two Wick contractions give

$$s = \frac{A_S c^3}{4G\hbar} = \frac{A_S}{d_{\min}^2} = \frac{F_{\max} A_S}{\hbar c}, \qquad (\Delta q_k)^2 = \frac{1}{2sk},$$
$$\mathcal{P}(s) = \frac{1}{2s^2} \sum_{k=1}^{\infty} \frac{e^{-2ik/s}}{k^2} = \frac{\mathrm{Li}_2(e^{-2i/s})}{2s^2}.$$

The dilogarithm denotes the absolutely convergent series here. Every mode retains nonzero width. The summands are bounded by a constant times the inverse square of the mode number when $s > 0$ (L2191, L2194, L2205–L2207). Expanding first in G at fixed area differentiates the phase and leaves at cubic order $-i \sum_{k=1}^{N} 1/(s^3 k)$ for cutoff N. Summing before expanding converts the logarithmic divergence in the cutoff into the finite term $-i \ln(s)/s^3$ (L2213, L2225, L2228–L2230). The operations differ at $s \to \infty$; in this fixed-area limit the stroke floor tends to zero. The chain requires all its variables, and 0.8 has no divergence at any scale. The dimensionless area s is a ratio of areas and in our reading counts no cells. This cluster is a reading under 0.1, 0.1a and 0.8 and corroborates no invariant (Use item 2). Absolute convergence holds at every positive s for this source phase. At fixed positive s and the stated phase the modulus of the contribution to $\mathcal{P}(s)$ from modes above cutoff N is at most $1/(2s^2 N)$; a resolved contribution above that bound from a band of modes above N would contradict the convergent sum.

The bounded diamond. A maximum clock reading supplies a projector. Semiclassically the covariant entropy bound suggests that the corner area limits the number of orthogonal states admitted by this projection (SA-23, L2244–L2245). The paper argues that its clock quadratic form is finite on a dense set of wavefunctions, as required for it to define a self-adjoint clock operator on the fixed-area space (SA-20, L2110–L2112). At finite G and $\hbar$ the estimates give *strong evidence* that the state of Eq. (5.6) converges in norm to the fixed-area Gaussian as $\mathfrak{l} \to \infty$ (SA-18, L2457–L2458); footnote 18 calls the classical estimate of the exact matrix element's increase a heuristic for the noncommuting operators (L2478–L2479), and the paper first chooses the smoothing length large, then raises the maximum reading at that same smoothing length, and thus argues at fixed diamond scale that the clock-window projection of the Gaussian keeps its full norm in the limit of Eq. (5.19) (L2491–L2494). The chosen pure extension ω_G of the fixed-area Gaussian to the full observable algebra selects a representation in which that algebra generates a type I factor (SA-19, L1688–L1689,

L1852–L1854). The paper defers whether other choices of the pure extension yield unitarily equivalent representations over the same range of readings (SA-19, L2544–L2546).

With these premises, the paper uses diffeomorphism invariance of the path integral to show that a macroscopic causal diamond with a given maximum size has finite-dimensional Hilbert space (SA-21, L24–L25). Cutting, applying the relative boost and gluing gives the trace of the area weight; since that weight is positive and at most the identity, finiteness of the dimension also bounds that trace (L2898–L2900). The bound on area within the clock window bounds the compensating exponential; the trace times the expectation of the compensating exponential gives the dimension, Eq. (5.39b,c). The corner area can take at most $d_{\mathcal{D}}$ distinct values (L2909, L2913, L2924). In our reading graininess of configurations on bounded support (0.1a) gives no independent FDT count. The floor permits arbitrary larger intervals. In JT gravity a causal diamond of bounded size admits infinitely many orthogonal states with identical clock probabilities, even with the dilaton fixed at both corners and the matter field in the same state; its algebra is a type I factor of infinite dimension (L280–L286). In our reading the tide does the work that yields a finite-dimensional Hilbert space: JT's generators have no transverse neighbours and read no tide. In Eq. (2.4c) use $\widehat{w} = w/L_{\mathrm{AdS}}$ for the dimensionless width. The reading in these units is $[\sinh(\widehat{w}/2) - \sinh(\epsilon_c \widehat{w}/2)]/\cosh(\epsilon_c \widehat{w}/2)$. At cap fraction 0.5 and widths $1, 2, 4$ (U-12) the readings are 0.2603, 0.5801 and 1.5888.

With the corner metric spherically symmetric and the diamond scale much smaller than the curvature radius, with smearing width much larger than the Planck length and much smaller than the centre distance, itself much smaller than the diamond scale, in the flat-space approximation of Eq. (5.26) at rapidity of order one with the left null tangent fixed, the boosted to unboosted cross-corner correlator ratio in the paper's freely falling vacuum, before smearing in the affine coordinate, for insertions centred at equal affine distances on either side of the corner, equals $4e^{\eta}/(1+e^{\eta})^2$; for smearings reflection-symmetric about the two insertion centres the fractional reduction in the magnitude of the two-point function is $\tanh^2(\eta/2)$, up to corrections quadratic in the smearing width over the centre distance (SA-24, L2616–L2617, L2698, L2702, L2716–L2717). At the unit rapidity of U-06 the point-kernel ratio is 0.7864, and the leading term of the finite-width fractional reduction is 0.2136. The transverse normalization cancels for disjoint insertions. With data on the cap and transverse smearing fixed in units of the diamond scale, the smooth-background correction to the correlator ratio near the corner is of order the squared distance of an insertion centre from the corner divided by the squared diamond scale (L2718, L2721). This cluster is a reading under 0.1a and I-3a and corroborates no invariant (Use item 2). The dimension result retains the choice of pure extension, the self-adjoint clock argument and the strong evidence at finite Newton coupling and reduced Planck constant for convergence in norm as the smoothing length tends to infinity. More than $d_{\mathcal{D}}$ mutually orthogonal preparations at the same clock and area limits would contradict it.

A limiting corner and its inward sheet. On a round cut take both null expansions in the normalization of Eq. (5.52a), with transverse null normal n^a and its expansion $\Theta_{(n)}$. The squared norm of the area-radius gradient is invariant under opposite boosts of the two legs. The exterior Schwarzschild solution gives

$$\nabla\varrho \cdot \nabla\varrho = -\frac{\varrho^2}{2}\Theta_{(\ell)}\Theta_{(n)} = 1 - \alpha_{\mathrm{ext}}(r_f = \varrho).$$

Equation (5.51) imposes at the limiting corner the zero outgoing expansion and strictly negative inward expansion of a spherically symmetric cut of the Schwarzschild horizon (L3042–L3045). The A-1 exterior ratio tends to unity from below as r_f tends down to R_s; no configuration occupies the endpoint. On the future inward sheet the following identification is our reading of Eq. (5.52b): when $\varrho_S = R_s$ in the limiting solution, $v_\varrho = \alpha_{\rm int}(r_f = \varrho)$ on the interior A-1 domain, from the cutoff up to the open fold. Its cap is then at the interior ratio ϵ_c when $r_c \leq \epsilon_c R_s$. No cutoff radius is inferred from the cap and no exterior flow is continued along the inward sheet (O-1, O-16). This cluster is a reading under 0.3, 0.3a, 0.4, I-3 and I-6 and corroborates no invariant (Use item 2). The expansion product gives the stated scalar exactly on round Schwarzschild cuts. An independently measured product and areal gradient inconsistent at matched normalization would contradict this identification.

The entropy weight and the mass ensemble. To identify the area term in Eq. (5.50) with the Bekenstein–Hawking entropy, the paper needs a condition on S that it can impose on the interior states in the trace before gluing on an exterior, and it uses a marginally trapped surface as its local notion of a black hole (L3037–L3038, L3041). With the future half of $\mathcal{D}$ glued to its time reflection along Σ_1, analytically continuing only the relative boost at S through a half turn on each copy yields the full 2π rotation (L3051–L3054). Since $\kappa F_{\max} = 2\pi$ and $\mathcal{K}/\hbar = s/(2\pi)$, the weight in the trace per admitted area eigenstate is e^{-s_i} for dimensionless area s_i (L3055). A round fold limit with mass $\mathcal{M}$ reads $s = 4\pi G\mathcal{M}^2/(\hbar c) = 4\pi R_s^2/d_{\min}^2$. A finite set of such limiting areas at fixed maximum reading selects finitely many masses in that sector. No black-hole spacing or individual spectral assignment follows here (O-9, O-15).

In Eq. (5.67b,c) the intrinsic curvature integrated on a cut of two-sphere topology is 8π. With the conical coefficient $53/[45(4\pi)^2]$, the other 8π from replica variation and the logarithm of the square root of band area s_b, the coefficient of $\ln s_b$ in the logarithm of the trace of the squared amplitude is 106/45 (SA-26). The trace measure adds one half, giving the power 257/90 of the upper bound s_* on s_i from focusing in the trace with its measure. Integrating from a fixed reference reading up to the maximum clock reading identifies the coefficient of the logarithm of the maximum reading over the reference reading in the logarithm of the trace with its measure as $q_\ell/(1-q_\ell)$ for the limiting clock ratio q_ℓ; the upper bound s_* scales as the square of the maximum reading, so the coefficient is twice its power in the trace with its measure, 257/45, and $q_\ell = 257/302$ (SA-27, Eq. (5.58), L3168–L3182, L3302–L3305). In footnote 23 the limiting squared ratio of the shear-free cap-to-corner reading to the maximum clock reading is $q_\ell/(2-q_\ell) = 257/347$, with numerator $(1-\epsilon_c)R_s$ and denominator $u_{\max}$ before squaring (L3238–L3240, L3248–L3253). Restoring the inverse area weight at each area and changing variables from horizon area to the mass measured at infinity removes one half, leaving 106/45 as the coefficient of $\ln s_b$ in the entropy at fixed mass with angular momenta summed (SA-28, L3313–L3317). The paper reports agreement with Sen's Euclidean calculation in this ensemble (SA-22, L3320–L3327). Its cited calculation lies outside the null-cone record. This cluster is a reading under 0.2, 0.5, I-7, I-5 and 0.8 and corroborates no invariant (Use item 2). The coefficients have one-loop precision in the specified ensemble. A distinct large-area log slope at fixed mass with angular momenta summed and the same field content would contradict that coefficient.

One settlement, two sides. With a complete orthonormal basis prepared independently at each boundary when boundary sources generate all bounded operators on the Hilbert space of each boundary, subtracting the superposition of product states weighted by their respective overlaps from the connected state leaves zero physical norm in Eq. (5.73) (L3361–L3373). At an AdS boundary the sum can be infinite; restricting the boundary energies to bounded intervals makes the sum of the squared overlaps finite, so the superposition of product states converges in the physical norm (L3376–L3378). One physical state has both representations. CI-2 concerns a match of complete states. For the Hartle–Hawking state of a two-sided Schwarzschild black hole, with a reflecting wall in each exterior and a horizon radius much larger than the Planck length, expanding the Hamiltonian to second order and retaining one odd-parity quadrupole, Eq. (5.75) pairs the state of a given number of gravitons on the left with its time reflection on the right at wall frequency ω (L3393–L3410). In our reading one settlement gives the paired record and no signal passes between the sides. No many-mode measure is written here (O-17). In our reading the time-reflected copy is the bra of an overlap: sewing to it computes the norm of the forward record. In our reading the time-reflected copy is no backward process. This cluster is a reading under 0.1a, I-4 and CI-2 and corroborates no invariant (Use item 2). The zero norm uses the physical inner product and the bounded energy intervals. A nonzero physical norm for that subtraction on those data would distinguish the representations.

The cosmological term. In the source the trace part of the multiplier is fixed by Λ (SA-03, L739–L740). In Appendix D.3 it expands about a causal diamond with spherical corner and fixes the affine parameter at the cap as in Eq. (3.27). The Λ term in (D.38) is suppressed by order $|\Lambda|\varrho_S^2$ relative to the spherical term (L5032–L5034, L5044–L5045). This dimensionless ordering requires the corner radius to be small compared with the curvature length. In 0.7 the effective term is the released stored potential per unit volume accumulated over the domain's history, the domain average of a regional amount; the amount rises where a region expands and falls where it contracts. T-2 states the additional distance dictionary. This cluster is a reading under 0.7 and corroborates no invariant (Use item 2). The small-corner statement concerns the first curvature correction. In T-2 an estimate of the void-minus-wall difference below the lower decision boundary excludes the shared-law point, and one above the upper boundary excludes the FDT sign.

Singularities and the horizon family. In Figure 8 the null generators followed to the past of the cut that bounds the past cap cross in pairs at distinct regular points in panel (a) and terminate at a spacelike curvature singularity in panel (b) (SA-12, L734–L736). The bounded diamond uses neither panel's continuation of the generators to evolve across its caps. In 0.6 and 0.8 the compact object is a hollow, double-sided density boundary. There is no singularity anywhere. In the expression comparing interiors as the black hole grows, the paper takes horizon radius in Planck units to infinity at fixed Newton coupling, holding the maximum clock reading divided by horizon radius fixed above unity minus the cap fraction (SA-25, L3106, L3113–L3118). In our reading the limit over a family of horizons specifies no accretion history. This cluster is a reading under 0.6 and 0.8 and corroborates no invariant (Use item 2). Only the family of stationary limiting radii enters the expansion. A resolved increase in the mass of one unmerged hole beyond the mass-difference criterion below would test the different evolutionary statement.

4 Cone-position translation

On A-1 every row refers to the field point in its own column. The Raychaudhuri equation determines the area radius from the conformal metric, the initial radius and its initial affine derivative; the chart applies only after that radius is known.

Region and point	Coordinate	Observable
Exterior, $r_f = 2R_s$	$\alpha_{\text{ext}}(r_f) = 1/2$	Seam on the exterior branch. The radius-gradient norm is 1/2.
Exterior, $r_f = 3R_s/2$	$\alpha_{\text{ext}}(r_f) = 2/3$	Circular null orbit: extremizing $(1 - R_s/r_f)/r_f^2$ gives this radius. It lies in the quantum-mechanical regime of 0.3a; U-35 records this radius.
Exterior, $r_f \downarrow R_s$	$\alpha_{\text{ext}}(r_f) \to 1^-$	At the limiting marginal surface the outgoing expansion vanishes and the inward expansion is negative; the trace weight remains finite at fixed area.
Interior, $r_f = R_s/2$	$\alpha_{\text{int}}(r_f) = 1/2$	Seam on the interior branch when the field point lies at or above the cutoff; the cut-to-corner radius ratio is one half for the limiting spherical corner.
Interior, $r_f = \epsilon_c R_s$	$\alpha_{\text{int}}(r_f) = \epsilon_c$	Fractional cap on the inward sheet, provided it lies in the chart domain.
Generic sheared corner	No monopole assignment	Solve for the angular radius and average with its own weights.

The orbit is a property of the solved optical geometry. The I-1a threshold belongs to the A-3 overlap-contrast application. The cap in one solution, the seam of its exterior atlas and the measured room of a particular interior pattern answer different questions. No transfer map follows from equality of two numerical ratios.

5 Matter's clock

The paper quantizes vacuum general relativity, and its clock is read along an incoming null generator, set at the past cap (SA-15, L241–L244). The paper places the clocks and reference frames with which events are compared in the same quantum system as spacetime (L235–L236), and on solutions of the constraints its Hamiltonian reduces to a surface charge (L138). In FDT the open stroke keeps no time, a closed pattern keeps time by circulating, and the clock and ruler that mark a cap are closed patterns of the medium (I-2, 0.1d, 0.1a,b). The cone supplies the geometry of the spacetime phase; closed patterns of the matter phase supply the clock, one substance in two phases (0.1, 0.8).

Barontini realizes a well-isolated Bose–Einstein condensate of about 2.4×10^4 ^{87}Rb atoms with a time-independent Hamiltonian, divided by a thin optical barrier into an observed and an unobserved region, with no measurable dissipation or loss over the roughly 100 ms of the experiment [10]. He orders the observed region's events by an entropic time built from its coarse-grained entropy alone, with no external clock; the entropic time grows monotonically almost everywhere, stops when no entropy is exchanged, and orders the observed region across repeated cycles of filling and emptying, while the entropy of the whole condensate

stays constant within the error bars [10]. With the entropy per atom of order unity, the entropic time counts, weighted by that entropy, the atoms that enter and leave the observed region: the record of the condensate's successive system-wide settlements (0.1a) [11]. Each atom keeps its own time by circulating, with period $h/(mc^2) = 5.1086 \times 10^{-26}$ s for ^{87}Rb (0.1d, I-5). The condensate's clock factor, at conserved count and fixed entropy per count, is its enthalpy per count, the reading of its flow, never the rate of a clock it carries (0.1c). The entropic time stops when no atoms cross; every atom keeps time through that interval.

Both constructions answer the problem of time from inside. On the null cone the clock is read relative to the corner, where the bulk Hamiltonian has become a surface charge; in the condensate the Hamiltonian is time-independent and the clock is read across the barrier. The corner and the barrier play the same part: each is the surface across which the clock is read. Matter enters this analysis through the one substance and the cold-atom record; no matter field is coupled to the paper's quantization, and no number of the paper changes.

6 Predictions

T-1. Energy exchange through an inspiral horizon

DC-2 discriminates SA-02. At a reflecting AdS boundary the boundary observables acting on a chosen ground state generate a sector. The paper's normal Hartle–Hawking state satisfies the KMS condition on all bounded operators on that sector, including operators that change area (L2949, L2995–L2999, L3006–L3018). That thermal identity fixes no signed mechanical flux for a binary. Our reading of 0.8 supplies an additional source condition: a hole that loses no mass by any channel gives up no energy through its horizon. The inspiral phase reads the energy exchange independently of a thermal trace. The mass unit $M_\odot$ is the solar mass, and $a_\star$ is the spin in units set by the angular momentum and the total mass. The investigator-chosen LISA source is a $10\,M_\odot$ body on a prograde circular equatorial orbit about a $10^6\,M_\odot$ hole with dimensionless spin $a_\star = 0.9$, over the final two years before plunge at optimal signal-to-noise ratio 50 (U-21–U-23). Here $a_\star = cJ/(G\mathcal{M}^2)$ for angular momentum J (0.4). In the flux model of Datta et al. [8], $\mathfrak{w}_H$ is one minus the squared reflectivity. Infer this single factor by fitting the orbital phase including the flux to infinity and the Kerr horizon flux multiplied by $\mathfrak{w}_H$. Both terms use the same orbital parameters. At these circular prograde frequencies every radiating harmonic has a pattern speed below the horizon speed. The Kerr horizon flux is negative: Tagoshi et al. [7], Eq. (4.6), give the leading ratio to the Newtonian flux as $-(a_\star + 3a_\star^3)\mathfrak{v}^5/4$, where $\mathfrak{v}^3$ is orbital angular frequency in units of $c^3/(G\mathcal{M})$ (U-25).

Write $\dot{E}_H$ for the energy flux into the horizon, $\dot{E}_H^{\mathrm{Kerr}}$ for the consensus value at the same orbit. The superscripts FDT and Kerr denote the two model points. The defining condition and its two solutions for this signed channel are

$$\dot{E}_H = \mathfrak{w}_H \dot{E}_H^{\mathrm{Kerr}}, \qquad \mathfrak{w}_H^{\mathrm{FDT}} = 0, \qquad \mathfrak{w}_H^{\mathrm{Kerr}} = 1.$$

Xia et al. [9] sample the full extreme-mass-ratio inspiral parameter space for the same masses, spin 0.90, initial semi-latus rectum $8.5G\mathcal{M}/c^2$, initial eccentricity 0.4, two years and optimal signal-to-noise ratio 50 (U-26). Their forecast bound on squared reflectivity is 1.00×10^{-3} at 68.3% (U-26, U-27). The circular design transfers ten times that bound as its Gaussian marginal standard deviation 0.01 at either endpoint (U-28). The fit retains covariance with

the other waveform parameters. This is a design precision; the eccentric posterior is no measurement of the prospective circular system. The design treats the estimator as untruncated at either physical endpoint.

For three standard deviations, an estimate above 0.03 excludes the no-loss point; one below 0.97 excludes the Kerr point. At that fit precision each one-sided false rejection is 0.00135 and power is 1.00 in either direction. Doubling the fitted uncertainty raises the displacement criterion to 0.06. The waveform factor is the single tested channel.

T-2. A regional standard-siren distance difference

DC-3 discriminates SA-03. In the source the trace part of the multiplier is fixed by Λ (L739–L740). Core 0.7 identifies the effective term with the released stored potential per unit volume accumulated over the domain's history, the domain average of a regional amount; the amount rises where a region expands and falls where it contracts. Our sightline dictionary reads more accumulated redshift per unit distance in expanding void-dominated volume. At fixed observed redshift the corresponding siren distance is smaller. This supplies a sign; no regional amplitude law enters (O-14).

Choose 200 binary-merger sirens in each of two disjoint classes (U-29), each with gravitational-wave luminosity distance $\mathfrak{L}_{\mathrm{GW}}$ and host redshift. A galaxy survey classifies the sightlines as void- or wall-dominated before the distance residuals are opened. Match the redshift distributions and use the same redshift relation, fitted independently, for both classes (U-29, U-30). Write $\mathfrak{L}_z$ for the distance from that relation, j for an event, $\mathfrak{r}_j$ for its dimensionless log residual, and angle brackets with subscripts void and wall for the class sample means. A common distance scale cancels. Write $\mathfrak{y}_3$ for the underlying void-minus-wall difference of class mean log residuals before differential bias, $\widehat{\mathfrak{y}}_3$ for its observed estimator and $\mathfrak{r}$ for the log residual before indexing an event. Event-specific distances are $\mathfrak{L}_{\mathrm{GW},j}$ and $\mathfrak{L}_{z,j}$. The two classes compare paths through neighbouring regions:

$$\mathfrak{r}_j = \ln(\mathfrak{L}_{\mathrm{GW},j}/\mathfrak{L}_{z,j}), \qquad \widehat{\mathfrak{y}}_3 = \langle \mathfrak{r} \rangle_{\mathrm{void}} - \langle \mathfrak{r} \rangle_{\mathrm{wall}}.$$

The homogeneous comparator, with one constant Λ, has $\mathfrak{y}_3 = 0$. FDT gives $\mathfrak{y}_3 < 0$ (U-30, U-31); the investigator's point $\mathfrak{h}_3 = -0.08$ sets the power (U-31). Gaussian event scatter is 0.15 with zero covariance between distinct events (U-32). The class bias from differential lensing and peculiar velocities has absolute bound $\mathfrak{c}_3 = 0.01$ (U-33). Only random residuals average down. Adding the two class-mean variances and taking the square root gives standard error 0.015. At three standard errors plus the bias allowance an estimate below -0.055 excludes the shared-law point; an estimate above 0.055 excludes the FDT sign. Equality stays inside both acceptance boundaries. The differential distance is the single channel.

At the adverse bias edge each one-sided false rejection is 0.00135. For the negative design point an opposing bias makes the estimator's mean less negative. The chance of crossing the lower boundary is 0.84; relaxing the bias bound and moving the boundary with it to the U-33 sensitivity setting 0.02 reduces power to 0.37. The Hubble number is regional. The sign test makes no measurement of its absolute regional value.

T-3. The quotient of two optical conversion rates

DC-6 discriminates SA-06. The quadratic insertions create and annihilate a graviton pair in one radial mode on the incoming cone (L2165–L2166). Advancing the annihilation source

gives each graviton a phase, and the two phases multiply in the amplitude. It does not measure two independently normalized rates. Core 0.1a states that a process run backward is never the mirror of the forward event; in I-2 the photon and graviton are the same stroke read in different regimes. Our observable dictionary transfers that event distinction to an absolute rate quotient of matched optical modes. Its sign and magnitude are not fixed by the cone amplitude.

Use a periodically poled lithium niobate waveguide phase-matched near pump wavelength 775 nm for degenerate down-conversion near 1550 nm (U-36). Select sixteen pump wavelengths across the phase-matching band (U-36, U-37). At each setting measure $\mathfrak{p}_{\downarrow}$, the spontaneous pair rate per unit pump power, and $\mathfrak{u}_{\uparrow}$, the normalized up-conversion efficiency of the same mode pair into the pump mode. Each direction has its own absolute calibration. The attributed reciprocity factor $\mathcal{Q}_{\leftrightarrow}$ converts the efficiency to the pair-rate units for these modes (U-38). Both rates must be positive. Write $\mathfrak{y}_{6,j}$ for the measured quotient in logarithmic units at wavelength setting j. The single-channel underlying log quotient $\mathfrak{y}_6$ at each wavelength and the sample mean $\bar{\mathfrak{y}}_6$ of its measured values over the sixteen settings (U-37) are

$$\mathfrak{y}_6 = \ln\!\left(\frac{\mathfrak{p}_{\downarrow}}{\mathcal{Q}_{\leftrightarrow}\mathfrak{u}_{\uparrow}}\right), \qquad \bar{\mathfrak{y}}_6 = \frac{\sum_j \mathfrak{y}_{6,j}}{16}.$$

The consensus uses one squared matrix element for both directions, giving $\mathfrak{y}_6 = 0$. Through that transfer the distinct-event reading gives a nonzero quotient in logarithmic units. The investigator's design magnitude is $|\mathfrak{h}_6| = 0.30$ for the mean true log quotient over the sixteen settings; either sign has the same power (U-39). Calibrate the common differential bias to an absolute bound $\mathfrak{c}_6 = 0.10$ before the first quotient is read (U-40). Independent Gaussian noise on each measured log quotient has standard deviation 0.10 (U-41). The random standard error is 0.025, with the common bias carried undivided.

An absolute sample mean above 0.175 detects a difference, the bias allowance plus three standard errors. At either bias edge the two-tail false detection probability is 0.00135. It includes the far tail at the opposite boundary. With bias against the design point the detection probability is 0.84. At the alternative U-40 bound 0.11 with its corresponding boundary the power is 0.58. Conversely, read the design magnitude as the absolute value of the mean true log quotient over the sixteen settings: when the absolute sample mean plus the bias allowance and three standard errors lies below it, that mean departure and every larger one are excluded at the stated confidence. A finite confidence interval with zero in its interior retains sufficiently small magnitudes of both signs. No sign of the regional distance observable enters this optical test.

T-4. The residual of a Loschmidt echo on an isolated condensate

Core 0.1a states that a process run backward is never the mirror of the forward event; T-3 reads that statement on two optical conversions, and T-4 reads it on matter that keeps its own time. Barontini lists accurate tests of reversibility through a Loschmidt echo among the next experiments on his condensate [10]. Run the low-barrier cycle forward through the filling of the observed region for a fixed laboratory interval, apply the reversal, evolve for the same interval and read the observed count. The residual fraction is $\delta = (N_{\mathrm{end}} - N_{\mathrm{start}})/N_{\mathrm{peak}}$, compared with δ_{model}, the echo of the source's mean-field model for the same Hamiltonian with the measured imperfections of the reversal included. The standard account takes the

reversed process as the mirror of the forward one, giving $\delta - \delta_{\text{model}} = 0$. Through that transfer the settlement reading gives a nonzero residual; its sign and size are not fixed here (D-1). Take Barontini's relative 1σ uncertainty of about 5% per point as the per-run standard error of δ, and $n = 100$ independent runs. The standard error of the mean residual is 0.005, and the decision boundary at three standard errors is 0.015. A mean residual farther than 0.015 from δ_{model} detects a difference; the two-sided false detection probability is 0.0027. A mean residual within ± 0.015 of δ_{model} excludes a residual of 0.03 or more, the investigator's design point, with power 0.99865. Reaching a boundary of 0.01 at the same per-run error takes 225 runs. No null-cone quantity enters this test.

Other candidate comparisons. DC-1 (SA-01) gives zero between-merger growth against an upper estimated comparator change of $5 \times 10^{-6}\, M_\odot$ below the $5.1 \times 10^{4}\, M_\odot$ criterion on the Galactic Centre baseline. DC-4 (SA-04) assigns discrete masses to merger remnants, but the bounded diamond's discrete areas specify no spacing for comparison to the continuum in gravitational-wave catalogues (O-15). DC-5 (SA-05) assigns a local causal aperture at the exterior A-1 photon sphere, $r_f = 3R_s/2$ (U-35), but P-4 supplies no map to a very-long-baseline photon-ring timing measurement beyond the null cone of the solved metric (O-8).

7 Cross-domain

In the helix triangle of 0.1d a closed pattern's strand runs at c, with translation along the axis and circulation perpendicular to it. Its phase speed times its group speed is c^2; unbinding gives equal speeds, $\omega = ck_{\text{ax}}$, with k_{ax} the axial wavenumber of the open wave. For the open stroke $\bar{\lambda} = c/\omega$. A confined pattern moves at translation speed v; the square of its circulation speed is $c^2 - v^2$, so the two squares sum to c^2. The kinematic share is v^2/c^2. The massive leg of the quantization chain has discrete rest masses, the open leg discrete periods and paths at fixed ratio. The chart reads continuously across this content. The minimum length is $2\ell_P = 3.233 \times 10^{-35}$ m and the minimum time is twice the Planck time.

A carried clock and ruler rescale together: $g_{\mu\nu} \mapsto \mathfrak{m}^2 g_{\mu\nu}$ preserves $d/t = c$. For four-velocity $\mathcal{U}^\mu$ and projector $\mathfrak{P}^{\mu\nu}$ perpendicular to it in unit-speed normalization, the bookkeeper's acceleration is $\nabla_{\mathcal{U}}\mathcal{U}^\mu = -\mathfrak{P}^{\mu\nu}\partial_\nu \ln \mathfrak{m}$. On its own clocks and rulers the pattern moves at constant speed through a density gradient; the bookkeeper reads acceleration toward smaller clock factor, where the pattern's clocks run slower. In the static exterior a slow pattern reads the lapse and a stroke reads the ratio of the ruler and clock adjustments, giving the factor of two in leading gravitational bending (0.1c, I-3). For perfect stress at zero net conserved count the medium's flow clock factor is proportional to temperature; at fixed entropy per conserved count it is proportional to enthalpy per count. A clock carried by that medium has its own thermal-motion time dilation.

On the A-1 spherical exterior a laboratory mass window reads $\alpha_{\text{ext}}(r_f) = \mathcal{M}c^2/(2F_{\max} r_f)$. Fall from rest far away has inward speed $c\sqrt{\alpha_{\text{ext}}(r_f)}$ and acceleration of magnitude $G\mathcal{M}/r_f^2$. A rotating source adds swirl. The gyroscope reads half its spatial curl on the slices of the falling clocks' time, giving leading Lense–Thirring precession. The four-velocity of that gravitational flow is irrotational. The spatial three-velocity gradient supplies the rotation; no interior flow reading enters (O-16). A gradient and a tide require neighbours. A quadrupole reads a skin against its centre path; the trace of relative acceleration reads density. CI-1 concerns the

relative transverse tide, whose composition is separate from the linear mode displacement.

In the helical window the energy of a pattern in a twist supplies its clock factor E/E_0, where E_0 is its reference energy. Add the work of inducing moments to E_0 and subtract the sum of the moments dotted into the local twist. Along a reference path the slow-limit force is minus the gradient of this energy, each moment held at its settled value, with inertial mass E/c^2. Patterns with different moments per energy fall differently along a twist gradient. A uniform twist turns a held moment and supplies no translational force. Identically oriented copies of one pattern at one point supply no differential reading. In the gravitational monopole window the clock factor belongs to the point.

For an equal-weight pair of opposite sense, I-4 gives the two wings' phases as ϕ and $\phi + \pi$. The clamps and both patterns form one system. On the circle the host clamp at angle $\mathfrak{a}$ selects phase density $|\cos(\phi - \mathfrak{a})|/4$; the polarization coordinate doubles the physical analyzer angle, while spin uses the Bloch angle. Local sign records at $\mathfrak{a}, \mathfrak{b}$ return correlation $-\cos(\mathfrak{a} - \mathfrak{b})$, with opposite sign for the same-sense pair. Each single-wing frequency is one half for every pair of settings. On all records every host gives the consensus cells with CHSH ceiling $2\sqrt{2}$. The uniform clamp-independent phase measure yields the triangular correlation and the all-record CHSH ceiling two.

Under the one-host, local-sign and locked-phase hypotheses, the kernel fixes the even part under a half turn. Any odd part changes a remote marginal as the host turns. Requiring a flat remote frequency fixes the full measure. On the sphere the square-integrable density is the absolute dot product of host axis and unit phase vector divided by 2π. The converse is confined to the hypotheses above (O-17). For a resolved history the two arriving frames yield the relative rotation R of the first frame times the transpose of the second. For unit analyzing axes $\mathbf{a}, \mathbf{b}$, the correlation is $-\mathbf{a}^{\mathrm{T}}\mathsf{R}\mathbf{b}$. Pooling histories replaces that rotation by its mean M. Its signed singular values determine the frequencies of the four equal-weight pairs, the purity and the negativity; with the largest two singular magnitudes $\mathfrak{s}_1, \mathfrak{s}_2$ the optimized all-record CHSH value for the pooled histories is $2\sqrt{\mathfrak{s}_1^2 + \mathfrak{s}_2^2}$. The singlet fidelity is $(1 + \operatorname{Tr}\mathsf{M})/4$. For turns around one axis the mean complex unit phase describes dephasing. The pooled record has lost its history label. No distribution of rotations is supplied by the diamond.

8 System-level reading (exploratory)

Scope. The following is an in-sample re-description of one round Schwarzschild corner. Its logarithm belongs to the fixed-mass ensemble with angular momenta summed.

X-1. A nominal solar-mass corner. The observable is the common area underlying the mode variance, boost charge and entropy weight. Fix the mass parameter $G\mathcal{M}$ to the nominal solar value and take the fundamental radial mode (U-04, U-05) [4]. The defining condition is $A_S = 4\pi R_s^2$ at the limiting round corner. Calculate R_s directly from the nominal mass parameter; use one common value of G for the stroke area and all functions of it (U-01–U-04) [3]. Use $G = (6.67430 \pm 0.00015) \times 10^{-11}$ in cubic metres per kilogram per squared second, $h = 6.62607015 \times 10^{-34}$ joule seconds and nominal $G\mathcal{M} = 1.3271244 \times 10^{20}$ cubic metres per squared second (U-02–U-04). Only the first input has measurement uncertainty. The comparator is the paper's: it writes the variance in terms of dimensionless area in Eq. (4.32), integrates the boost charge aspect over the corner in Eq. (3.43) and changes variables from

horizon area to mass measured at infinity with angular momenta summed in Eq. (5.69).

Reading	Conversion	Nominal value
Source radius	$2G\mathcal{M}/c^2$	2953.3 m
Dimensionless area	$A_S/d^2_{\min}$	1.049×10^{77}
Area logarithm	$\ln s$	177.35
Fixed-mass logarithmic contribution	$(106/45)\ln s$	417.75
Boost charge in quantum units	$\mathcal{K}/\hbar = s/(2\pi)$	1.669×10^{76}
Fundamental mode variance	$(\Delta q_1)^2 = 1/(2s)$	4.767×10^{-78}

Holding the nominal mass parameter fixed removes Newton's constant from the radius. The fractional uncertainty of s and of the charge equals that of G in magnitude and has opposite response to increasing G; the variance is proportional to G. The absolute uncertainty in $\ln s$ is the fractional uncertainty of G to first order. The logarithmic contribution multiplies that uncertainty by its ensemble coefficient. These correlated conversions give no separate measurements of the same area.

Guards. The reference mass parameter fixes a scale. No solar-mass black hole or measured mode variance enters. The floor bounds strokes, the area is the limit from the round chart, and the state count still needs the self-adjoint clock argument, the chosen pure extension, the finite-coupling norm estimate and the trace at fixed maximum reading.

9 Convergence statement

Fix the stress tensor, boundary and initial data, gauge and cosmological input of the target. By I-3, FDT and general relativity solve the same equation and return the same curvature. The null generators and their shear-dependent affine interval follow from that solution. In the chosen representation FDT returns the Born frequencies, which use the state's inner product (I-4). At leading order the Wigner average uses the fraction removed at each classical clock reading, and for incoming coherent data the mean-field equation retains its one-loop correction. Sewing the same amplitudes with a complete intermediate basis gives Eq. (4.29) by the identity operator. This composition and the area conversion corroborate no invariant (Use item 2). Finite-coupling existence, the self-adjoint clock argument and the chosen representation retain the qualifications above.

At areas $s = 10, 100, 1000$ (U-07) the imaginary part of the exact pair amplitude multiplied by the cube of the area is, in order, -2.6100, -4.9120 and -7.2146. Its first large-area expression $-[1 + \ln(s/2)]$ gives -2.61, -4.9120 and -7.2146. At mode cutoffs 10^3 and 10^6 (U-09) the harmonic coefficients of the expansion taken first are 7.4855 and 14.3927. The latter comparison holds the order of expansion fixed; the former sums at finite area before taking a large-area limit.

At fixed corner area the source takes the quantum state to be generically a superposition over gravitons, so that an upper limit on the clock reading restricts the graviton states that can be prepared (SA-07, L1917–L1919). FDT reads superposition as ignorance of helical phase at observation (I-4). For the Hartle–Hawking state of a two-sided Schwarzschild black hole, with a reflecting wall in each exterior and a horizon radius much larger than the Planck length, with the Hamiltonian expanded to second order and one odd-parity quadrupole retained,

at wall frequency ω the source thermal amplitude pairs the state of $\mathfrak{n}$ gravitons on the left with its time reflection on the right (SA-08, L3393–L3407). FDT reads those gravitons as the one carrier, the same spin-one excitation of the density field, with no separate particles (I-2, 0.1b). The paper proposes a background-independent quantization of vacuum general relativity on four-dimensional Lorentzian spacetimes and reports that loop corrections to graviton scattering amplitudes about Minkowski spacetime in pure general relativity lead to ultraviolet divergences that make the theory perturbatively nonrenormalizable (SA-09, L14–L16, L105). In FDT the geometry is carried by the one quantised carrier and the cascade steps space and time with mass; there is no divergence at any scale (Use item 6, 0.8). For smooth globally hyperbolic vacuum spacetimes the paper can choose a cover for each solution and recover the full reduced phase space by gluing overlapping causal diamonds (SA-10, L632–L634). FDT has no vacuum: where the matter stress vanishes, no variable in the chain vanishes (0.1, 0.1d). The paper notes that in graviton scattering about Minkowski spacetime in four-dimensional pure gravity, even at small external momenta a virtual pair can carry large and nearly opposite momenta (SA-11, L2142–L2151). FDT has one carrier; interactions are curvature plus geodesic motion (I-2). In the continuation in Figure 8(b) the null generators followed to the past of the cut bounding the past cap terminate at a spacelike curvature singularity (SA-12, L734–L736). FDT has no singularity anywhere; a compact object is a hollow, double-sided density boundary, with a dilute centre and a saturated skin (0.8). With Eq. (3.4), the source's equations in Eq. (3.5) imply $R_{ab} = \Lambda g_{ab}$ (SA-13, L757–L758). FDT has no cosmological-constant term; the effective one is the released stored potential per unit volume accumulated over the domain's history, the domain average of an amount that differs from region to region (0.7). With the boundary conditions held fixed, the paper shows that a state prepared on a connected slice can also be represented by an entangled superposition on two disconnected spatial components, realizing the algebraic criterion for ER = EPR (SA-14, L212–L214). FDT reads that superposition's record as one settlement of one system, two patterns of shared bivector grade and their two clamps, and no signal passes through the settlement between the two components (I-4). The paper defines a gravitational clock along an incoming null generator from the past cap to the corner: fixing the tangent in a local Lorentz frame at the cap sets the affine scale, and taking the parameter to vanish there makes its value at the corner the clock reading (SA-15, L241–L244). In FDT the open stroke runs at c and keeps no time; a closed pattern keeps time by circulating (I-2, 0.1d). Each cap bounds only one causal diamond; another can cover the subregion excised by cutting off the tips (SA-16, L219–L221). FDT assigns a core circle to each end of the interval (0.3a). Footnote 9 takes a diamond in a convex normal neighbourhood, with the absolute contraction of the null and timelike tangents fixed to unity at each vertex and tidal curvature of order the inverse squared Planck length; its size can be much smaller than the Planck length with the caps at the fixed radius fraction and the curvature at the central point preserved (SA-17, L1103–L1105). The floor in FDT is the infimum of physical strokes, approached by the least closed pattern and occupied by none (0.1a). Whether the corner lies on the event horizon depends on which exterior is glued to the same interior data: later infall can trap outgoing null generators that would otherwise reach future null infinity (SA-01, L3037–L3040). FDT converts accreting matter to spacetime and energy; a hole loses no mass and grows only by merging (0.8).

Bell's inference stands for a measure independent of the settings. FDT declines measurement independence: the host clamp sets the projection measure, and for the equal-weight

pair FDT returns the consensus table cell by cell, local transport on the same histories and local detector responses included, and no divergence follows from the measure (I-4).

For the Galactic Centre comparison the external stellar-orbit determination is $(4.297 \pm 0.012) \times 10^6\, M_\odot$ (statistical uncertainty; U-13, U-14) [5]. The external accretion upper bound is $2 \times 10^{-7}\, M_\odot$ per year (U-15) [6]. Hold that ceiling for the investigator's merger-free 30 years and retain one minus the assumed radiated fraction 0.1 (U-13–U-20). The endpoint statistic is the difference between two independent Gaussian mass determinations with the quoted statistical error at each end. Its variance is the sum of the endpoint variances; the covariance term vanishes by design. Three standard errors yield the mass threshold in the candidate comparison. The exact two-sided false-rejection rate rounds to 0.0027. Even at maximal retained inflow the two readings are experimentally indistinguishable on this baseline. Neither the rate bound nor that difference is a measurement of mass gain.

For Barontini's condensate, with the same trap, barrier settings, atom numbers and entropy method, FDT returns the measured record: the entropic time grows monotonically almost everywhere, flows faster with exchange and stops without it, the total entropy is constant within the error bars, and the Schrödinger equation in entropic time reproduces the measured width [10, 11]. The regions of the condensate share the laboratory lapse to 8.73×10^{-22} across the barrier, so no gravitational channel changes those numbers. Declining the past hypothesis and the reading of the exchange as reversible changes no measured value; T-4 is the one divergence there.

10 Status ledger

Item	Domain and status
T-1	Prospective, single-channel, designed at the stated waveform precision. No-loss point zero; Kerr convergence value unity.
T-2	Prospective, designed at the investigator's point. Negative underlying difference of class means; the common distance relation with one constant Λ gives zero for that difference. The design amplitude is assumed (O-14).
T-3	Prospective, through the optical transfer, which predicts existence only. Reciprocity gives zero underlying log quotient.
T-4	Prospective, designed at the investigator's point. The echo transfer predicts existence only. The mirrored reversal gives zero residual beyond the modelled imperfections.
D-1	To be derived: the sign and size of the echo residual, from the settlement's dynamics.
Matter	The matter clock is read from the cold-atom record; the entropic time as a settlement record is this analysis' reading, and no matter field is coupled to the paper's quantization.
X-1	In-sample solar corner. The charge, logarithm and variance use one input area.
Cone	All observation-map clusters and chart translations are in-sample. The finite-dimension claim retains the representation, existence and clock-operator premises.
Readings	The tidal composition rests on CI-1; identification of matched complete states rests on CI-2.
Charts	The A-3 overlap, A-4 confinement and A-5 mode tokens have only the open-interval range. The skin is a schematic limit.
Flow	The temperature and enthalpy-per-count readings assume perfect stress and their stated conservation conditions.

O-1	To be derived: the finite-core cutoff, the regular core chart, or the outward phase-transfer law.
O-2	To be derived: a geometrically constructed odds for the overlap-contrast application.
O-3	To be derived: a canonical odds for the confinement application.
O-4	To be derived: the local profile from the omnium constitutive law with boundary, surface and core data, reducing to the measured nuclear profile.
O-5	To be derived: multipole and tidal remainders of the closed-form pair expression, their reading of the band outside a rotating source's horizon, the overlap complex and how P-4's many-cone settlement signs a pair it does not join.
O-8	To be derived: the constitutive derivation of the causal speed and index and its reconciliation with lensing.
O-9	To be derived: the confinement operator, its domains, boundary data and spectrum; every mass ratio, including the two held-out targets, the proton-to-electron ratio and squared muon-to-electron ratio.
O-14	To be derived: the mass-shadow response function and its closure, the release function of 0.7 (the mass-loss rate density and compression contrast of the unwinding bodies and converted accreting matter), the regional law of the released amount and of the Hubble number.
O-15	To be derived: what a domain merger conserves, the conversion flow law with the merger's rates, the spectrum of black-hole masses and the derivation of the CMB as the substrate's standing-wave state. No merger mass budget enters the tests.
O-16	To be derived: the kinematic reading of the share on the interior chart. The exterior flow reading stops at the fold.
O-17	To be derived: the dynamics of the pair's settlement, what selects the host clamp, how the measure is carried between the clamps, and the measure for a pair of unequal weights and for more than two patterns.

11 Conclusions

The null-cone construction gives a clock whose shear delay can be compared between sheared and shear-free cones at fixed corner area and the same initial area element and expansion. The round-corner boost supplies a second relation: dividing its charge by the quantum of action fixes the dimensionless area weight for a full turn. Recovering a finite dimension requires more than either relation. For a macroscopic causal diamond of given maximum size the finite-dimension argument uses the chosen pure extension, the argument for a self-adjoint clock on the fixed-area space and the strong evidence at finite Newton coupling and reduced Planck constant that the smoothed state converges in norm to the fixed-area Gaussian as the smoothing length tends to infinity; finiteness of the dimension also bounds the thermal trace. The cone fixes the geometry; matter keeps the time. The four prospective experiments require a signed binary horizon flux, an estimate of the difference in mean log distance residual between matched sightline classes, a sample mean from two absolutely calibrated optical conversion rates, and the mean residual of a Loschmidt echo on an isolated condensate. Their exclusion criteria pertain to those observables.

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