

# A Finite-QEC Substrate Program for Particle Physics and Cosmology: Current Canon and Audit Methodology

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## Abstract

This paper summarizes the current state of a finite-substrate program in which particle physics and cosmology are modelled as consequences of a quantum-error-correcting register geometry rather than as fields on a pre-assumed continuum. The framework starts from an eight-bit local code, its constrained crystallisation into a register-bearing cubic phase, and a finite service ledger for boundary and bulk correction events. The present canon contains exact finite-code results, reproducible numerical results, conditional derivations with named open lemmas, and a substantial retraction ledger. The aim of this overview is not to present the framework as closed, but to state clearly what is currently derived, what is computed, what is conditional, and what has been retired.

The strongest current themes are: a reconstruction ladder in which the minimal balanced finite record cell is the unique self-dual doubly-even  $[8, 4, 4]$  byte; a derived bare service rate  $\alpha_0 = 1/137$ , with dressed- $\alpha$  renormalisation kept separate; the recovery of Standard-Model-like matter structure from the finite code; a canonical  $28 = 2 \times 14$  service clock; an intrinsic Einstein-form result from substrate entanglement, while the observed Planck hierarchy remains a cosmological-selector problem; a dynamic dark-energy branch  $w(a) = -1 + a/28$ ; an HBC scalar-clock route to  $(n_s, A_s) = (27/28, (3/4)\alpha_0^4)$  under local saturated-printer, channel-lock, and spatial-whitening premises; and a dark-sector picture in which K04 debris is pinned/subdominant while the CMB-relevant mobile component is a pressureless R4 zero-mode reservoir if a conserved massive dust charge is admitted. The main remaining load-bearing questions are also explicit: sector billing maps, including the dressed- $\alpha$  Maxwell-contact route that is numerically sharp but still lacks the endpoint-covariance  $\rightarrow F^2$  normal-ordering theorem; the CMB dust-premise, full-likelihood, and acoustic microscopic-lift gates; the continuum chiral/mirror-gapping problem; the halo non-double-counting choice; the CP/holonomy sector; and the detailed normalisation of black-hole horizon channels and fast-scrambling topology.

The framework also states how it can fail. Its standing falsification targets include: a SHOES-side resolution of the Hubble tension (the selector chain predicts  $H_0 \approx 67.3$  on the CMB side); a robust phantom epoch  $w < -1$  at any pre-completion redshift; failure of the exact finite Boltzmann–Keldysh lift or full likelihood to sustain the continuum 63/64 QND service-lapse acoustic clock; failure to justify or admit the pressureless zero-mode reservoir supplying  $\omega_{\text{dark}} \simeq 0.121$ , or failure to avoid halo double-counting; loss of the black-hole flux coefficient if the all-contact severing rule fails; and drift of  $(n_s, A_s)$  away from  $(27/28, (3/4)\alpha_0^4)$  under tightening CMB constraints.

# Contents

<b>1 Purpose and Scope</b>	<b>2</b>
<b>2 Relation to Existing Programs</b>	<b>3</b>
<b>3 The Substrate Picture</b>	<b>4</b>
<b>4 Right Bi-Cubic Crystallisation</b>	<b>5</b>
<b>5 The <math>[8, 4, 4]</math> Code and the 28-Clock</b>	<b>5</b>
<b>6 Current Results at a Glance</b>	<b>7</b>
<b>7 Matter and Gauge Structure</b>	<b>7</b>
<b>8 Cosmology and Dark Energy</b>	<b>8</b>
<b>9 Proton-Primary Gravity</b>	<b>9</b>
<b>10 Dark Matter, MOND, and Debris</b>	<b>11</b>
<b>11 Black Holes and Horizon QEC</b>	<b>12</b>
<b>12 Relativity from the Substrate</b>	<b>12</b>
<b>13 Methodology: Why the Audit Ledger Matters</b>	<b>13</b>
<b>14 Open Frontiers</b>	<b>13</b>
<b>A Reproducibility Ledger: Starter Table</b>	<b>16</b>

## 1 Purpose and Scope

The program summarized here is ambitious enough that ordinary exposition is not sufficient. It needs an audit trail. Many earlier claims in the corpus were later demoted, split, or retired when their derivations were found to consume hidden inputs, double-count a coefficient, or confuse a numerical match with a theorem. The current canon is therefore best read as a mathematical and computational snapshot, not as a promotional list of successes.

The intended reader is a mathematically literate physicist or graduate student. The main text gives the physical picture and headline mathematics. Detailed finite enumerations, lattice simulations, and operator audits are kept in scripts and appendices. The code repository [16] is part of the paper’s evidential structure, not supplementary decoration.

This overview is the entry point to a seven-paper series. Six companion preprints carry the sector-by-sector detail: foundations and methodology [12]; matter, gauge structure, and spectroscopy [14]; cosmology, dark energy, and inflation [10]; the dark sector [11]; gravity, horizons, and black holes [13]; and the recovery of special and general relativity from the substrate [15].

The paper uses six status labels throughout.

Label	Meaning
LOCKED	Exact finite derivation or theorem with no named load-bearing gap.
COMPUTED	Reproducible finite-algebra or numerical result with a script and expected output.
CONDITIONAL	Derivation reduced to named premises or lemmas that remain open.
DIRAC-CLASS / horizon bridge	Relation uses the QCD-to-cosmological large-number bridge; the text must state whether the horizon quantity is an input, a scaffolding variable that cancels, or an output.
RETIRED	Historical claim retained for provenance, no longer a live result.
OPEN FRONTIER	Named unsolved target with a concrete closure or falsification condition.

## 2 Relation to Existing Programs

This program sits at the junction of several established lines of work, and it is worth being explicit about both the kinship and the differences.

**Informational substrates.** The idea that physics is informational at bottom goes back at least to Wheeler’s “it from bit” [43], with modern descendants in ’t Hooft’s cellular-automaton interpretation [38] and Lloyd’s computational-universe program [24]. The present framework belongs to that lineage but is deliberately finite and specific: one particular eight-bit code, one particular lattice, and audited counting rules, rather than a general thesis.

**Quantum error correction and holography.** The thesis that spacetime geometry is the book-keeping of a quantum error-correcting code is now mainstream in holography: the Ryu–Takayanagi relation [34], its reinterpretation as bulk error correction [1], and explicit toy codes [29], all descending from the holographic principle [36, 37]. The present program shares the central thesis but differs in three ways: there is no AdS asymptotics; the code is fixed and small rather than emergent and large; and the program attempts something that literature does not, namely numerical prediction of dimensionful constants. That attempt is what makes the audit ledger necessary.

**Spin networks and lattice gauge theory.** The gauge-sector computations use non-reduced spin-network bases in the sense of Penrose and of Rovelli–Smolin [30, 33], evaluated on a fixed background lattice in the Hamiltonian tradition of Wilson and Kogut–Susskind [23, 45]. The cut-off/volume escalation arguments are standard strong-coupling and cluster-expansion rigor [28]. The chiral-fermion and mirror-gapping discussion is positioned against the Nielsen–Ninomiya obstruction [27] and its modern circumventions — domain-wall, boundary, and Ginsparg–Wilson fermions [18, 21, 35] — and against the symmetric-mass-generation literature [9, 42].

**Emergent gravity and large numbers.** On the gravity side the ancestors are Dirac’s large-number hypothesis [8] and the thermodynamic route to the Einstein equations [20, 40]. The historical weakness of large-number relations is that they consume a cosmological measurement. Section 9 addresses this head-on with an explicit input/output ledger.

**Defect cosmology.** The crystallisation and debris sector uses the Kibble–Zurek mechanism [22, 46] and the standard taxonomy of walls, strings, and textures [41], transplanted from field vacua to bond configurations of a discrete substrate.

### 3 The Substrate Picture

The framework does not begin with a smooth manifold. It begins with local finite registers, a constrained code space, and allowed correction or transition events. The continuum, if recovered, is an infrared description of a crystallised phase of these registers. The foundations companion [12] defines these objects in full. For an independent account of how much of standard physics rests on unresolved continuum pathologies — and why a finite ontology is worth the trouble of constructing — see Baez [4].

The local code is an eight-bit structure related to the  $[8, 4, 4]$  extended Hamming code [25] — the same code that underlies the  $E_8$  root lattice and the integral octonions [3]. At the level relevant for this overview, the important facts are:

1. local states are finite and code-constrained;
2. invalid or strained configurations are not merely absent but are part of the correction ledger;
3. local correction events can be counted, scheduled, and audited; and
4. the visible continuum phase is the ordered, register-bearing crystalline phase, not the pre-geometric background.

This shift matters. A relation such as a particle mass, a cosmological equation of state, or a dark-sector abundance must say which ledger it reads: code content, strain content, boundary service current, wall shadow, or ordinary continuum field content. Several retired claims failed precisely because they used evocative thermodynamic language without specifying this map.

The reconstruction layer is now sharper than in the first draft of this overview. The philosophical floor is still an axiom floor — stable local records, compatible tests, finite noisy substrate, and repeatable readout are not derived from something deeper here. But once that floor is accepted, the finite record cell is no longer an arbitrary “start with a byte” assumption. In the binary balanced Type-II CSS class, distance-4 erasure protection forces minimal length  $n = 8$ , and the unique minimal cell up to relabelling is the self-dual doubly-even  $[8, 4, 4]$  code. Its commuting read/write stabilizers form the full  $[[8, 0, 4]]$  record cell. The Born rule is likewise no longer a free probability postulate inside the accepted QEC Hilbert substrate: stabilizer non-contextuality plus Gleason fixes the form, and the closed-record-pair/Naimark construction gives

$$p_s = \text{Tr}(\Pi_s \rho) = \|\Pi_s \psi\|^2$$

with the square arising from the surviving closed forward/backward record pair. The residual is now explicit: why nature chooses this complex, locally tomographic QEC substrate is the reconstruction wall, not a separate Born-rule wall.

The bare service rate is also no longer a loose seed. The monitored record-pair service alphabet contains

$$\text{Sym}^2(16) = 136$$

record-pair labels plus the idle channel, so equipartition over the monitored one-hot service register gives  $\alpha_0 = 1/137$ . This closes the shared bare-rate problem at reconstruction grade. It does not

automatically close every downstream use of  $\alpha_0$ . Each sector must still prove that it bills this service observable, and the physical dressed value  $\alpha^{-1} = 137.035999\dots$  remains a separate renormalisation problem.

## 4 Right Bi-Cubic Crystallisation

The most useful physical image is that the register-bearing world crystallises into an embedded cubic phase. The ordered phase is not assumed; it is selected by local bonding and cycle constraints. The name *bi-cubic* refers to the two cubic structures in play: the ambient lattice is periodic  $\mathbb{Z}^3$ , and the ordered phase is a tiling of it by disjoint eight-vertex register cells that are themselves combinatorial cubes ( $Q_3$  graphs). Crystallisation means that a degree-constrained bond configuration relaxes into this cube tiling, and each surviving cube cell becomes one instrumented register. Vertices, branches, and faces have distinct roles.

**Vertices.** Vertices are the local register sites. They carry the finite code data and the local event ledger. In the ordered phase, a vertex is an instrumented cell: it can record strain, participate in syndrome checks, and contribute to the service ledger.

**Branches.** Branches or bonds encode adjacency. They are the support for line currents, line defects, and finite move operations. In the dark-sector simulations, degree-constrained bond subsets of an embedded periodic cubic lattice provide the physical ensemble. This distinction is crucial: a looser configuration model admitted spurious  $K_{3,3}$ -ordered phases, while the embedded  $\mathbb{Z}^3$  substrate forbids those patterns geometrically.

**Faces and plaquettes.** Faces and plaquettes carry loop constraints. They make cube cells, gauge-cell plaquettes, and boundary checks meaningful. Plaquette moves preserve local degree while changing the bond pattern. They also reveal sector structure: some parity sectors are conserved by local moves, while the crystal anchors occupy the same physical sector.

**Crystallisation and debris.** The ordered crystal is the visible, register-bearing substrate. Mis-ordered domain walls and trapped defects are not automatically matter particles. They must pass mass, coupling, durability, and mobility gates. Current embedded simulations support a picture in which fast cooling traps massive, gauge-blind, locality-protected wall debris by the Kibble–Zurek mechanism [22, 46]; the defect taxonomy (walls, winding lines, healable short trails) is the discrete analogue of the standard one [41]. Later audits sharply restricted its role: unrecorded wall energy does not simply gravitate in full; gravity reads the recorded boundary strain or shadow ledger. The current debris sector is therefore not a free hidden particle gas. It is a geometric relic sector whose abundance and gravitational effect depend on pairing, orphan policy, and wall-read depth.

The companion foundations and dark-sector papers [11, 12] carry the fuller formal treatment: bond-subset state space, cycle counts, sector parities, Kibble-Zurek ramp protocol, healing spectra, aging, percolation, and the island-floor statistics.

## 5 The $[8, 4, 4]$ Code and the 28-Clock

One of the strongest finite-code results is the service-clock structure

$$28 = 2 \times 14.$$

The factor 14 is the affine-hyperplane count associated with the weight-four logical service channels of the eight-bit register. The factor 2 is the transverse-mode doubling. The resulting 28 channels are not an entropy count and not an angular degeneracy. They are service channels.

The current finite-instrument picture is:

$$8 \text{ local bit labels} \longrightarrow 112 \text{ incidence flags} \longrightarrow 28 \text{ service channels.}$$

Under a one-jump finite-bandwidth scheduler, covariance makes the channel weights uniform, so the serial absorbing service clock has first gap

$$\Delta_1 = \frac{1}{28}.$$

This supplies a finite origin for several cosmological formulae. What remains load-bearing is not the integer 28 itself, but the physical lift from finite service channels to the relevant cosmological ledger.

## 6 Current Results at a Glance

Sector	Status	Current summary
Finite code and clock	COMPUTED / CONDITIONAL	The $[8, 4, 4]$ byte is the unique minimal balanced record cell under the finite-record axioms; the 28-channel service structure is finite and reproducible; cosmological use still requires ledger-specific lifts.
Record measure and $\alpha_0$	COMPUTED / CONDITIONAL	Born is conditionally closed by Gleason plus closed-record-pair readout, and the bare service rate $\alpha_0 = 1/137$ follows from the $136 + 1$ monitored record-pair alphabet; dressed $\alpha$ and sector billing maps remain separate audits.
Matter content	COMPUTED / CONDITIONAL	The byte dictionary gives $4 \times 2 \times 2 = 16$ fermion slots and $48 = 3 \times 16$ , with anomaly arithmetic and several spectroscopy anchors surviving audit; continuum chiral-gauge closure remains conditional.
Dark energy	CONDITIONAL	The live branch is $w(a) = -1 + a/28$ , with non-phantom activation; exact status depends on the homogeneous R4-line lift and no-extra-channel completion.
Inflation	CONDITIONAL	The tilt route gives $n_s = 27/28$ under saturated radial holographic boundary crystallization (HBC) printing and power-ledger action; amplitude has the sharp candidate $A_s = (3/4)\alpha_0^4$ if channel-lock/critical-latch and spatial-whitening hold.
Gravity	CONDITIONAL	The Einstein form follows from RT/min-cut, KMS, and service-current entanglement thermodynamics at Jacobson grade; the observed Planck hierarchy and selector/acoustic-scale relation remain cosmological/horizon gates.
Dark matter / MOND	CONDITIONAL / OPEN FRONTIER	K04 debris is pinned/subdominant; CMB matter is the conditional $\nu_R + N_{\text{zero}}$ dust route, with the conserved massive dust charge not derived from active R4 dynamics; MOND normalization $\chi_{R4} = 1$ is discharged under the directed-edge/Fock ledger, while halo double-counting remains a branch choice.
Black holes	CONDITIONAL / OPEN FRONTIER	Local KMS, finite ladder, freeze-shell scaling, echo-null, and Schwarzschild greybody transfer are sharp; absolute flux needs the all-contact service-class theorem and species/polarization ledger, and fast scrambling needs new nonlocal horizon service.
Trans- $\Lambda_{\text{QCD}}$ quanta	COMPUTED / OPEN FRONTIER	High-energy quanta are represented by framed causal-set/null-chain external legs rather than crystal Bloch modes; support/LSZ are closed at current grade, while precision QED, finite-density transfer, and Lorentz-violation bounds remain phenomenology.

## 7 Matter and Gauge Structure

The matter side is where the framework is most finite and least dependent on cosmological interpretation; the matter companion [14] carries the full construction and spectroscopy. The code structure supplies a finite state space with internal labels corresponding to chirality, weak structure,

colour, and generation-like organization. The current byte dictionary is more explicit: one matter cell has four Pati-Salam columns, two chiral rows, and two CSS defect classes, giving 16 fermion slots and  $48 = 3 \times 16$  across three generations. Exact anomaly arithmetic is a useful example of the current discipline: the surviving  $-2/9$  result is an exact chiral-anomaly identity, while the former “universal  $2/9$ ” framing was retired because two of its three advertised legs did not survive audit.

Similarly, the strong-CP sector is split into what is bare-substrate finite-code structure and what is continuum lift. The mass-phase half is now explicit at the finite level: the code mass operators are Hermitian, so  $\arg \det(M_u M_d) = 0$ . Together with the real gauge-half reading this gives  $\bar{\theta} = 0$  at the bare substrate. The continuum result, however, depends on the accepted lattice mechanism for chiral fermions or a successful symmetric-mass-generation route. It is not presented as a fully locked continuum theorem.

The mirror-gapping and SMG sector has advanced substantially through finite and sparse-matrix computations. The remaining frontier is not whether a finite cell can host a symmetric mirror gap; it is whether the gauge-coupled TCH continuum route stays inside the no-bulk-transition basin at weak coupling. The present observable is the electric-subtracted gauge-invariant mirror gap along the pure fundamental Wilson  $SU(3)$  axis; the registered SMG Hamiltonian induces no adjoint or irrelevant pure-gauge couplings, so the remaining obstruction is the ordinary weak-coupling confinement/no-bulk-transition frontier.

The CP/baryogenesis sign has also been localized. The real documented walk does not generate the needed complex CP-odd sign. The required operator class is a complex  $\Delta L = 2$  Majorana holonomy portal for the sterile sector. It is sufficient and necessary inside the admissible class, but its boot origin, phase, and selected orientation are still open.

## 8 Cosmology and Dark Energy

The cosmology companion [10] carries this sector in full. The live dark-energy branch is

$$w(a) = -1 + \frac{a}{28}, \quad w_0 = -\frac{27}{28}.$$

This is best read as an activation law. Before activation, records do not gravitate as a separate dark-energy carrier; at service completion the record replaces the underlying strain as the gravitationally active carrier. This assignment avoids double-counting the same source and forbids phantom behaviour in the canonical branch. That prohibition is a clean discriminator: the canonical branch requires  $w(z) \geq -1$  at every pre-completion epoch, so a robust future detection of a phantom crossing of the kind some  $w_0 - w_a$  fits flirt with [7] would falsify the activation identification outright. Today’s value  $w_0 = -27/28 \approx -0.9643$  is consistent with current constraints [7, 31].

The same finite clock also appears in the inflationary tilt candidate:

$$n_s = 1 - \frac{1}{28} = \frac{27}{28}.$$

The current theorem form is conditional but sharp. A finite 28-channel clock is not enough by itself. The required lift is a saturated radial holographic-boundary-crystallization (HBC) printer for which  $d \ln k = d \ln a$ , and the QEC generator must act on the scalar power ledger rather than on a coherent amplitude. Under those conditions,

$$\frac{d \ln \Delta_{\mathcal{R}}^2}{d \ln k} = -\frac{1}{28}.$$

Numerically  $n_s = 27/28 = 0.96429$ , against the measured  $n_s = 0.9649 \pm 0.0042$  [31]: a  $-0.15\sigma$  agreement obtained from a channel count rather than from a potential.

The scalar amplitude is now in the same conditional family rather than a free normalisation. The projector and Poisson/Fano factors are closed, and locality plus homogeneous fixed-total printing gives  $S_j(k = aH) = 1$  for nonzero modes after the compensated projector removes the total mode. The stop rule is

$$\lambda_{\text{shell}} = N_{\text{shell}}\alpha_0^4 = C_F = \frac{4}{3},$$

from saturated queue balance under the local scalar-printer identification. Thus

$$A_s = A_\nu = \frac{3}{4}\alpha_0^4 = 2.13 \times 10^{-9},$$

again  $+1.0\sigma$  from the measured amplitude [31]. This is the sharp candidate under the local single-clock saturated-printer, channel-lock, and spatial-whitening premises; an all-channel load or horizon-mode covariance changes the amplitude while the tilt can remain intact.

The dangerous CMB gate is now sharper. A baryons-plus-sterile-only dark sector fails: with  $\nu_R$  alone the equality redshift sits near recombination, and the third acoustic peak is wrong. The live conditional route adds a pressureless R4 zero-mode reservoir, understood as an admitted conserved dust charge rather than a consequence of the documented active R4 Lindbladian. The source law

$$m_{\nu_R} = \alpha_0^2 \Lambda_{\text{QCD}}, \quad n_{\nu_R}/n_\gamma = \alpha_0/208$$

gives  $\omega_{\nu_R} \simeq 0.0242$ , and the directed-incidence split gives  $\omega_{\text{zero}} = 4\omega_{\nu_R} \simeq 0.0969$ , so  $\omega_{\text{dark}} \simeq 0.121$  and  $z_{\text{eq}} \simeq 3428$ . CAMB runs then reproduce the TT peak heights and high- $\ell$  tail at the percent level. The remaining failure surface is not the third-peak shape but the dust premise, halo bookkeeping, and acoustic scale: the selector  $H_0$  gives  $100\theta_*$  high by about 0.3%. Numerically a pre-latch projection

$$H_{\text{CMB}} = \frac{63}{64} H_{\text{selector}}$$

closes the acoustic scale while preserving the TT shape. The service-side operator has now been identified more sharply: active-address completion gives  $P_{\text{busy}} = I - |111111\rangle\langle 111111|$  with normalized trace  $63/64$ . At continuum service-current grade the acoustic phase is precisely the long-wavelength QND readout of that native service-lapse current: the photon-baryon acoustic ruler is a conformal-time phase clock, and the relativity/service-current gates identify the conformal lapse with the scalar service-clock covariance. The remaining clause is now the exact finite substrate lift to the Boltzmann-Keldysh action and the full CMB likelihood, not the continuum lapse identification itself.

## 9 Proton-Primary Gravity

The gravity sector has split into form and magnitude. The form is now much stronger than in the first overview draft. The verified RT/min-cut area law, local KMS temperature, emergent Lorentz structure, and service-current modular Hamiltonian put the substrate in the Jacobson/Faulkner class:  $\delta Q = T\delta S$  on local horizons forces

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

at leading emergent-continuum grade. Thus the Einstein form and the matter coupling are not simply imported. What this route supplies by itself is the bare lattice-scale Planck mass,  $M_{\text{Pl,bare}} =$

$O(\text{GeV})$ , consistent with the independent heat-kernel stiffness calculation. The  $10^{19}$  hierarchy from this bare scale to the observed  $M_{\text{Pl}}$  remains the cosmological/horizon or selector problem.

Historically, several gravity formulae were audited as horizon-consuming Dirac-class relations in the lineage of Dirac [8]. The cleaner current route reverses the presentation; the gravity companion [13] carries the full route and its falsification gates. Use the proton mass to fix the chiral scale:

$$\Lambda_p = \frac{m_p}{2\sqrt{2}}.$$

Then the framework's QEC/horizon-accounting chain predicts the gravitational scale and the Hubble constant. The input/output ledger verifies that a Hubble parameter can appear in derivational scaffolding and still cancel from the final input list. The working formula can be written schematically as

$$M_{\text{P}} = \Lambda_p \sqrt{\frac{990 \alpha_{\text{conv}}^4}{\alpha_0 r_6}},$$

Here  $r_6 \approx 2.84 \times 10^{-43}$  is a pure number: the stationary fraction of faults per register per tick that survives all six levels of the concatenated correction hierarchy, computed from the finite queue model with no astrophysical input. The integer structure of the prefactor is itself accounted:  $990 = 9 \times 110$ , where 9 is the lifetime register-touch budget of one complete deep service (eight single-bit repairs plus one post-service readout, the unreadable global-complement slot contributing nothing) and  $110 = 16 \times (55/8)$  arises from the horizon severing-channel count  $55/8$  (the 56 directed monogamy incidences of the eight-bit register minus the one global blind degree of freedom). An equivalent form makes the cosmology-free content explicit:

$$M_{\text{P}}^2 = 110 \alpha_0^2 \Lambda_p^2 N_{\text{lock}}, \quad N_{\text{lock}} = \frac{9\alpha_0}{r_6} \approx 2.31 \times 10^{41} \text{ ticks},$$

in which the Planck scale is the accrued record capacity over a service span fixed entirely by the microphysics. The same ledger gives

$$H_0 = \frac{\Lambda_p r_6}{9\alpha_0}.$$

The current script ledger reports

$$G = 6.67218 \times 10^{-11} \text{ SI (bare)},$$

$$G = 6.67919 \times 10^{-11} \text{ SI (dressed)},$$

and

$$H_0 = 67.266 \text{ km s}^{-1} \text{ Mpc}^{-1}.$$

The comparisons carry the content. The two conventions bracket the CODATA value  $G = 6.67430(15) \times 10^{-11}$  [39], with per-convention offsets of  $-0.03\%$  and  $+0.07\%$  — inside the present  $\alpha$ -convention spread but  $14\times$  and  $33\times$  the experimental precision of  $G$ , so resolving that convention turns this into the programme's sharpest internal test. The predicted  $H_0 = 67.27$  sits  $-0.17\sigma$  from the Planck value  $67.36 \pm 0.54$  [31] and is firmly on the CMB side of the Hubble tension [32]: a SH0ES-side resolution would falsify the chain. The Hubble constant is therefore an output, not an observed input, in this presentation; an explicit script varies a Hubble dummy tenfold and verifies that no output moves.

Two further checks deserve emphasis. First, a two-anchor consistency: the same chiral scale is reached from two unrelated measured anchors. Anchored on  $G$  (with measured  $M_{\text{P}}$  the lone

dimensionful input) the solved scale is  $\Lambda^* \in [0.33168, 0.33185]$  GeV across the  $\alpha$  conventions; anchored on the proton it is  $\Lambda_p = 0.331729$  GeV — inside that window. Torsion balances and mass spectrometry agree, through derivation chains that never meet, to  $1.6 \times 10^{-4}$ . Second, a locking constraint: read literally as a running accrual, the area-law relation would imply  $\dot{G}/G \sim H_0$ , excluded by lunar laser ranging by more than three orders of magnitude [44]; the accounting is therefore epoch-locked at service completion, which the activation identification supplies.

This is still not license to erase the conditional status. The result rests on the proton-side baryon relation, the depth-six residual chain, the generation-vertex/QEC billing machinery, sector billing maps, and the bare-vs-dressed alpha convention. The current claim is stronger and narrower than the old one: Einstein form is intrinsic to the service entanglement, and proton-first predicts  $G$  and  $H_0$  inside a conditional finite-QEC accounting chain, while the observed Planck hierarchy is not yet an unconditional intrinsic prediction.

## 10 Dark Matter, MOND, and Debris

The dark sector now contains several distinct mechanisms that should not be merged prematurely; the dark-sector companion [11] carries the full treatment.

**Debris.** Embedded crystallisation simulations show that fast cooling can trap mis-ordered wall debris. The toy configuration model’s large defect fraction was superseded because it admitted non-physical  $K_{3,3}$ -ordered states. The embedded  $\mathbb{Z}^3$  ensemble is the physical one. It crystallises much more cleanly, and trapped defects are domain-wall-like, durable, and geometrically constrained.

The decisive later point is that bare unrecorded wall energy is not the gravitating ledger. Gravity reads recorded boundary strain. Thus debris dark matter is controlled by wall shadow depth, pairing/orphan policy, and island-floor statistics. Some branches are already ruled out by over- or under-shoot; the surviving branches are measurable, not freely adjustable. Later mobility audits sharpen the physical interpretation: K04 debris is pinned to the substrate frame and thermally immobile, so it is not the dominant mobile halo component. Its observational role is a subdominant fossil relic and upper-bound/null component, not a Bullet-Cluster-like collisionless particle halo.

**Zero-mode dust and the CMB.** The CMB third-peak pressure is now the dark sector’s most dangerous empirical gate. The live route is a conserved R4 zero-mode reservoir distinct from the active MOND line count, but that conserved massive charge is not supplied by the documented active R4 dissipative dynamics. Its minimal effective action is Brown–Kuchar/geodesic dust: rest-count energy only, no gradient stiffness, so  $w = c_s^2 = 0$ . The directed-edge service incidence gives the relative abundance  $\omega_{\text{zero}} = 4\omega_{\nu_R}$ , while the  $\alpha_0/208$  source map supplies the absolute scale conditionally. This route closes equality and peak heights at forward-spectrum grade if the dust charge is admitted, but it forces a branch choice. Either the zero-mode is the CDM-like mobile halo mass and active R4/MOND is not separately fitted as a galaxy force, or the framework must derive a  $> 95\%$  galaxy depletion/screening theorem for the zero-mode to avoid double-counting.

**R4/MOND.** The MOND/BTFR route [17, 26] is a different mechanism. Its clean form is a Poisson-conditional line-current theorem: if the R4 halo sector supplies matched creation/erasure rates and nonexclusive one-dimensional line occupancy, then the effective line susceptibility is  $\chi_{R4} = 1$ , and the cubic AQUAL/MOND action [5] follows. The latest premise-discharge audit makes this less free:  $\chi_{R4} = 1$  follows from directed-edge R4 support plus the one-record Fock service ledger. The remaining issue is not the local normalization but the global halo branch. Active R4/MOND

may be a late response, but it cannot be fitted as an independent halo component on top of a fair-sample zero-mode dust halo without a new depletion or screening theorem.

## 11 Black Holes and Horizon QEC

The black-hole sector is best presented as a consequence of the same finite horizon accounting, with Bekenstein–Hawking thermodynamics [6, 19] reformulated as ledger statements. State-counting derivations of horizon entropy from a discrete quantum geometry have a precedent in the loop-quantum-gravity count of Ashtekar et al. [2]; the finite-code form here differs in that the channel count  $55/8$  is fixed by the register’s directed monogamy ledger modulo its one blind degree of freedom. The gravity companion [13] carries the horizon-channel detail.

Several pieces are now sharper than in the first overview draft. The finite cell isometry  $V_{\text{cell}}$  and the Schwarzschild shell channel  $V_{\text{Sch}}(M)$  have been formulated at finite-cell grade: horizon-adjacent cells enter a local map, and the radial scheduler supplies the shell rates. The local horizon QEC steady state gives the half-Boltzmann KMS scheduler, and the finite Hawking ladder is a Boltzmann ladder on integer strain with fixed line ratios and a spectral gap at  $F = 3$ , the minimum cut of the  $Q_3$  register graph. Freeze-shell scaling and the escape cone give the expected  $M^{-2}$  luminosity scaling, and standard Schwarzschild spin/partial-wave greybody factors can be applied outside the derived source shell. The current-channel picture also predicts no large coherent late-time echoes: there is no reflective membrane in the local service model.

The remaining open pieces are correspondingly specific. The near-horizon source attempt rate lands at the Stefan–Boltzmann coefficient only if horizon severing uses the all-contact Landauer–Moore service class, giving the conditional scheduler factor  $(10/27)\alpha_0$  and  $P/P_{\text{SB}} = 0.997096$ . That all-contact transfer, the species/polarisation ledger, and the absolute flux normalisation remain conditional. Fast scrambling is also not produced by the purely local service graph; it requires either a derived nonlocal/expander horizon graph or it remains a frontier rather than a claim.

## 12 Relativity from the Substrate

The preceding sectors assume Lorentz invariance and a background metric; the relativity companion [15] asks where they come from when the fundamental description is a discrete register walk with a preferred update order, and recovers both in computed form. *Special relativity* is the universal reversible propagation clock: the invariant speed is one lattice step per service tick, and because all stable matter, gauge bosons, and measuring devices are excitations of the same reversible walk/QEC clock, internal observers cannot see the microscopic preferred frame. The matter sector is an exactly isotropic massless Weyl cone: the three gauge-compatible spatial hops form an anticommuting chirality Clifford triple, forcing  $H(k)^2 = (\sum_d \sin^2 k_d) I$  and hence  $E = |k|$  at leading order. The physical photon is the Gauss-projected transverse compact- $U(1)$  Maxwell mode on the dual simple-cubic gauge web — not the raw K6  $T_{1u}/E_g$  vertex band, which fails the Ward/Gauss test — so its low-energy velocity anisotropy is an irrelevant  $O((a_0 k)^2)$  lattice artifact and Lorentz invariance is restored for  $\omega \ll \Lambda_{\text{QCD}}$ . The previous “QCD-scale cutoff” objection has been refuted rather than ignored: TeV photons are not Bloch modes of the crystal. The current representation is a framed causal-set/null-chain external leg with support and LSZ normalisation closed at present grade, while precision QED phenomenology, finite-density corrections, and experimental Lorentz-violation bounds remain open tests. *General relativity* is the coarse-grained covariance of that clock under strain: straining the cone yields the metric directly,  $g^{ij} = \delta^{ij} + 2\varepsilon^{ij}$ , so the metric perturbation *is* the substrate strain field, splitting under  $O_h$  into the conformal lapse and the spin-2 graviton

(whose own infrared isotropy is conditional: the bare  $E_g$  band is marginally anisotropic like the bare K6  $T_{1u}$  band, but gravity’s induced kinetic term is a relevant operator, so the isotropic induced term dominates provided the bare seed is removed by the canonical tachyon stabilisation). The matter strain-response is a conserved, symmetric, massless-conformal stress tensor; the linearised Bianchi identity and the substrate’s strain-ledger conservation are one diffeomorphism invariance, so  $G_{\mu\nu} = 8\pi G T_{\mu\nu}$  (with the  $8\pi$  fixed in §1.5) is a consistent field equation rather than an imposed one. The equivalence principle follows once gravity couples to the full energy — kinetic plus confinement/Yukawa mass — and not to the bare hopping, which would be *anti-mass*; universality is then forced by the soft-graviton theorem. The same paper shows the four horizon objects of the previous section (area law, Hawking ladder, firewall isometry, gravitational source) to be one register syndrome read four ways. As elsewhere the tiers are explicit: the kinematic spine is computed and machine-verified, while the Nielsen–Ninomiya infrared flow, Sakharov induced gravity, and Weinberg universality enter as flagged imports.

### 13 Methodology: Why the Audit Ledger Matters

The project has a large retraction ledger. This is not cosmetic. It is the mechanism by which the current canon was made sharper. The main failure mode in earlier thermodynamic and dark-sector claims was qualitative appeal outrunning quantitative ledger specification. Claims that sounded like Landauer or entropy derivations often decomposed into a real scale plus an asserted coefficient. The current protocol requires every thermodynamic claim to specify:

1. the carrier being counted;
2. the event unit;
3. the scheduler;
4. the observable map;
5. the competing ledgers that must not be double-counted; and
6. the script or finite proof that checks the arithmetic.

This is why the overview is paired with a reproducibility appendix and a code repository. The methodology is part of the physics claim.

The same discipline has clarified the parameter ledger. In the native record-QEC core, no ordinary fitted real coefficient remains. Numbers that looked free have either become sector-native invariants (incidences, capacities, Casimirs, or Brillouin-zone loop integrals) or have been demoted to explicit second-anchor/frontier status. The remaining hard walls are not a diffuse cloud of numerology. They are typed: sector billing maps, dressed- $\alpha$  renormalisation, the electroweak and nuclear second scale, the CP/holonomy sector, and a few observable-map completions. That typing is a result of the audit method, not an after-the-fact slogan.

### 14 Open Frontiers

The current open problems are narrower than the historical open problems. The most important are:

- justify the conserved massive zero-mode dust charge, construct the exact finite substrate lift to the Boltzmann–Keldysh action behind  $H_{\text{CMB}} = (63/64)H_{\text{selector}}$ , and settle the halo branch so zero-mode dust, active R4/MOND, and  $\nu_R$  are not double-counted;
- settle the weak-coupling SMG/TCH frontier: the finite mirror gap is certified in the tested domain, but the pure fundamental Wilson  $SU(3)$  no-bulk-transition input still carries the continuum lift;
- complete the strong-sector scale-setting lift: finite closed-cell singlet selection, Wilson surfaces, and baryon  $Y$ -strings are in hand, and the ordinary cubic  $SU(3)$  Cornell extractor is validated, but the same fixed scheme on current TCH blocks still gives negative or unstable string tensions;
- treat dressed  $\alpha$  as a conditional finite-contact problem: the Ward/Kubo self-energy is not the monitored service projector, but closed record pairs select a candidate local Maxwell contact  $2 \sum Q^2 - 1 = 31$ ; the missing theorem is the endpoint-covariance  $\rightarrow F^2$  normal-ordering map;
- derive the complex  $\Delta L = 2$  Majorana holonomy portal that can select a CP-odd baryogenesis sign;
- complete the HBC scalar-printer channel-lock/critical-latch and spatial-whitening identities, or derive the nonlocal horizon-mode scalar-current operator that changes the amplitude;
- close the black-hole all-contact severing/species/flux ledger and, if fast scrambling is required, derive nonlocal horizon topology or a non-spatial address-space expander; and
- develop the trans- $\Lambda_{\text{QCD}}$  null-chain layer into full precision-QED and Lorentz-violation phenomenology.

**Standing falsification targets.** Independently of the open derivations, the following are already on the record and decidable by external data: (i) a SHOES-side resolution of the Hubble tension falsifies the proton-primary chain ( $H_0^{\text{pred}} \approx 67.3$ ); (ii) a robust phantom epoch ( $w < -1$ ) at any pre-completion redshift falsifies the activation identification; (iii) the CMB acoustic scale must be repaired by a derived selector theorem, not by fitting  $H_0$ ; (iv) the pressureless zero-mode reservoir must be justified and reproduce  $\omega_{\text{dark}} \simeq 0.121$  without halo double-counting; (v) the inflationary pair  $(n_s, A_s)$  must remain at  $(27/28, (3/4)\alpha_0^4)$  within tightening CMB constraints, with no observable primordial  $B$ -mode tensor signal; and (vi) the discrete Hawking ladder, in any setting where it could ever be probed, carries a forbidden-line gap below  $F = 3$ .



# A Reproducibility Ledger: Starter Table

Claim	Status	Script	Expected result
Canon consistency	COMPUTED	ai_methodology/ptms	PTMS hard findings equal zero for the current canon snapshot.
Record reconstruction	COMPUTED / CONDITIONAL	python_code/record_reconstructio n_tier_split.py; python_code/mini mal_balanced_record_cell_theorem .py	Unique minimal balanced [8, 4, 4] record cell; bare $\alpha_0 = 1/137$ split from sector billing and dressed $\alpha$ .
Dressed $\alpha$	CONDITIONAL contact candidate / OPEN FRONTIER	python_code/dressed_alpha_servic e_kubo_moment_no_go.py; python_cod e/dressed_alpha_maxwell_contact_ selector_theorem.py; python_code/ dressed_alpha_endpoint_contact_m ap_attempt.py	Service occupation and physical Ward/Kubo current-current billing are distinct observables. Closed record-pair counting selects the finite Maxwell-contact count $2\sum Q^2 - 1 = 31$ , but the endpoint-covariance $\rightarrow F^2$ normal-ordering theorem is still open, so CODATA dressed $\alpha$ is not Locked.
Born/record measure	COMPUTED / CONDITIONAL	python_code/born_closed_record_p air.py; python_code/r13_record_act ion_measure_status.py	Orthogonal projectors, Naimark readout, closed-record-pair square, and record-action skeleton with named holonomy/clock residuals.
Proton-primary gravity ledger	COMPUTED / CONDITIONAL	python_code/g_route_input_ledger .py	Varying an $H_0$ dummy leaves $G$ , $H_0$ , and $\Lambda$ outputs unchanged.
HBC amplitude and tilt	CONDITIONAL	python_code/hbc_amplitude_status .py; python_code/item131_primordi al_tilt_logscale.py	$S_j(k = aH) = 1$ , $\lambda_{\text{shell}} = C_F = 4/3$ , and $(n_s, A_s) = (27/28, (3/4)\alpha_0^4)$ under channel-lock/spatial-whitening and local saturated-printer premises.
CMB reservoir gate	COMPUTED / CONDITIONAL	python_code/cmb_dark_reservoir_s tatus.py; python_code/item123_cmb_ lock_attempt.py	$\nu_R + N_{\text{zero}}$ gives $\omega_{\text{dark}} \simeq 0.121$ and TT-shape recovery if the conserved dust charge is admitted; the 63/64 busy projector and continuum QND service-lapse readout are derived, while the exact finite Boltzmann-Keldysh lift remains conditional.
Premise discharge	COMPUTED / CONDITIONAL	python_code/premise_discharge_sw eep.py; python_code/alpha0_downstr eam_billing_map_audit.py	R4/MOND local $\chi_{RA} = 1$ , HBC locality, and sector billing-map status.
Black-hole observables	COMPUTED / CONDITIONAL	python_code/bh_observable_residu al_map.py; python_code/bh_fast_sc rambling_topological_obstruction .py	Local KMS, ladder, freeze-shell, greybody transfer, echo-null, and the conditional $(10/27)\alpha_0$ flux ledger; local horizon topology cannot produce an $O(1)$ scrambling gap.
Trans- $\Lambda_{\text{QCD}}$ external legs	COMPUTED / OPEN FRONTIER	python_code/foundations_trans_la mbda_precision_residuals.py	Null-chain support/LSZ closed at current grade; precision-QED and finite-density phenomenology remain.
SMG/TCH continuum frontier	COMPUTED / OPEN FRONTIER	python_code/smg_tch_weak_continu um_frontier_audit.py; python_code/ smg_rg_basin_reduction.py	Extended finite-domain mirror gap and zero induced pure-gauge couplings; remaining input is the pure Wilson weak-coupling/no-bulk-transition lift.
Strong-sector scale setting	COMPUTED finite / OPEN FRONTIER	python_code/record_grammar_cubic _su3_static_potential_pipeline.p y; python_code/record_grammar_tch _su3_static_potential_pipeline.p y; python_code/record_grammar_tch _su3_mustational_static_potential	Finite confinement/Y-string structure is intact and the cubic Cornell extractor is validated; current TCH straight and variational ensembles are not

The full script index will be generated in a separate file, `script_index.md`, and each companion paper carries a more detailed claim-by-claim table.

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