From Timeless Pattern to Dynamic Reality: Deriving the Recognition Length and the Lock–In Mechanism

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Abstract

Recognition Science posits that physical reality crystallises out of a timeless *pattern layer* (PL) when pairs of potential states form a stable *recognition lock*. From five axioms—*Existence, Dual-Recognition, Minimal Overhead, Self-Similarity, Lock-In*—we derive a unique *recognition length* $\lambda_{\rm rec}$ by equating the one-bit Landauer cost with the entanglement-entropy bound of a minimal causal diamond. A dual-log cost functional proves regulator-independence and fixes the stationary scale at $q_\star = \varphi/\pi$, while a Regge-calculus minimisation shows that an equilateral face of area $\sqrt{3}\,\lambda_{\rm rec}^2/4$ saturates the bound. Each lock-in releases the universal quantum $E_{\rm lock} = \chi\,\hbar c/\lambda_{\rm rec}$ with $\chi = \varphi/\pi$; the cumulative power $\kappa E_{\rm lock}$ drives cosmic acceleration through a simple master equation and maps directly onto the observed dark-energy density. Finally, we show that G, $\hbar$, k_B and α emerge as algebraic functions of $\lambda_{\rm rec}$ and χ, eliminating circular dependence and yielding sharp, near-term tests in MICROSCOPE-2 WEP measurements, nanometre-scale Casimir probes and advanced-LIGO propagation lags.

1 Introduction

Physics progresses by compressing diverse phenomena into ever leaner principles: Newton united celestial and terrestrial mechanics with one law; Maxwell fused electricity, magnetism and light; Einstein recast gravity as geometry. Yet our present "fundamental" description still relies on dozens of empirical constants,[1] two incompatible formalisms (quantum theory and general relativity) and an *ad hoc* role for the observer. Recognition Science pursues the next step. It treats *information* as primitive and views geometry, quantum indeterminacy, classical determinacy and even the arrow of time as book-keeping devices that minimise the energetic cost of *recognition* between potential states. If this premise is right, *every* dimensionful quantity must collapse to an algebraic function of a *single* information-theoretic scale, leaving no numbers to tune by hand.

That scale is the **recognition length** $\lambda_{\rm rec}$. Conceptually, it is the edge of the smallest causal diamond able to lock one irrevocable bit. It bridges two descriptive layers:

(i) the **Pattern Layer** (PL): a timeless, self-similar information manifold in which all states exist only as weighted possibilities; and

(ii) the **Reality Layer** (RL): the growing subset of those possibilities that have mutually *recognised* one another, locking information into definite classical fact.

[1] CODATA 2024 lists twenty-eight for the Standard Model alone.

Whenever the cost of maintaining a superposition across a diamond of size R exceeds one-bit Landauer cost, the system *locks in* and releases the fixed quantum

$$E_{\text{lock}} = \chi \frac{\hbar c}{\lambda_{\text{rec}}}, \qquad \chi = \frac{\varphi}{\pi}.$$

Thus λ_{rec} seeds the space-time metric, while E_{lock} sets the budget by which pattern becomes physics and potential becomes actuality.

This paper pursues three goals:

(a) derive λ_{rec} from first principles, without inserting $\hbar$, G or any empirical constant;

(b) show how λ_{rec} together with the golden-ratio factor $\chi = \varphi/\pi$ reproduces $\hbar$, G, k_B and α algebraically, leaving *zero* tunable numbers;

(c) identify concrete, near-term falsifiers—MICROSCOPE-2, Casimir-X, LIGO-V and high-z cosmology—that can validate or refute the framework within a decade.

What follows promotes λ_{rec} from a heuristic placeholder to the linchpin of a parameter-free, testable synthesis of information, geometry and physical law.

2 Axiomatic Recap and Physical Motivation

We collect here the six postulates that define Recognition Science and state the key existence theorem that fixes a single recognition length λ_{rec}.

2.1 Axiom 0 (Existence)

Every finite causal diamond contains at least one irreducible "recognition" bit. An empty region cannot reliably store the information required to certify its own emptiness.

2.2 Axiom 1 (Persistence)

The total information content of the universe can never fall to zero. A perfectly empty state is logically unstable and therefore excluded.

2.3 Axiom 2 (Dual Recognition)

A potential state becomes definite only when it is recognised by at least one other state. Mutual recognition supplies the minimal non-circular confirmation of existence.

2.4 Axiom 3 (Minimal Overhead)

When several configurations achieve the same distinction, nature selects the one with the lowest information–energy cost.

2.5 Axiom 4 (Self-Similarity)

Valid recognition patterns remain valid under global dilations. In the absence of an external ruler, no absolute scale can be fundamental.

2.6 Axiom 5 (Lock-In)

If the information cost of maintaining a superposition inside a causal diamond of radius R exceeds one bit ($k_B \ln 2$), the system pays the bit cost, collapses, and releases a fixed energy quantum

$$E_{\text{lock}} \;=\; \chi\,\frac{\hbar c}{\lambda_{\text{rec}}}, \qquad \chi = \frac{\varphi}{\pi},$$

where $\varphi = (1+\sqrt{5})/2$ is the golden ratio.

2.7 Existence and Uniqueness of the Recognition Length

Under Axiom 0 and the Minimal Overhead principle, Theorem F (*Minimal-Bit Uniqueness*) proves that exactly one dual-recognition cell can inhabit any finite causal diamond. Theorem G (*Golden-Ratio Optimal Scale*) then shows that minimising the recognition cost over all self-similar lattices fixes the unique dilation ratio $q_* = \varphi/\pi$, from which a single finite length λ_{rec} follows algebraically.

A detailed proof of both theorems appears in the companion *Axiom 0* paper; here we quote the result:

$$\boxed{\text{Recognisable reality admits exactly one finite } \lambda_{\text{rec}}.}$$

The remainder of this paper explores the physical consequences of that unique scale.

3 Causal–Diamond Entropy Bound without Horizons

Set-up. Pick two timelike-separated events $p \prec q$ with proper-time gap $\Delta t = 2R/c$ and *identify* the radius with the recognition length,

$$R \;\equiv\; \lambda_{\text{rec}}.$$

Their causal diamond is

$$\mathcal{D}(p,q) \;=\; J^{+}(p) \,\cap\, J^{-}(q),$$

the smallest space–time region that can host an irrevocable distinction created at p and verified at q.

Minimal one-bit diamond. Axiom **A3** (Minimal Overhead) plus Theorem F (companion paper) require *exactly one* dual-recognition cell inside any finite diamond—hence one bit of entropy $S_{\min} = k_B \ln 2$. The area-minimising mid-slice compatible with global dilation symmetry is an equilateral triangle of edge λ_{rec}, whose area is

$$A_{\triangle} \;=\; \frac{\sqrt{3}}{4}\,\lambda_{\text{rec}}^{2}. \tag{1}$$

Quantum-information bound. For any quantum field in its Minkowski vacuum restricted to $\mathcal{D}(p,q)$, the quantum Bousso bound gives the vacuum-subtracted von Neumann entropy

$$S_{\mathcal{D}} \;\le\; \frac{k_B c^3}{4\hbar G}\,A_{\triangle}, \tag{2}$$

even though the diamond contains no trapping horizon.

Saturating with one bit. Setting $S_{\mathcal{D}} = k_B \ln 2$ in (2) and inserting (1) yields the unique geometric–constant relation

$$\boxed{\hbar G \;=\; \frac{c^3\sqrt{3}}{16\ln 2}\,\lambda_{\rm rec}^2}, \tag{3}$$

obtained *without* reference to black-hole horizons or adjustable parameters.

Interpretation. Equation (3) shows that, once the recognition length $\lambda_{\rm rec}$ is determined—in Sec. 4 via the scale-invariant cost minimisation—the product $\hbar G$ is predicted outright. The recognition length is therefore the sole geometric carrier of one definite bit of information, bridging the timeless recognition lattice to emergent space–time dynamics.

Uniqueness recap. By Theorems F and G (companion paper) the recognition length is unique; we denote it simply by $\lambda_{\rm rec}$ throughout the rest of this work.

4 Scale–Invariant Cost and the Unique Recognition Ratio

The recognition lattice is dilation–self-similar; any legitimate cost functional must therefore be *scale invariant.* Let $X > 0$ denote the radial dilation factor between adjacent lattice shells.[2] Minimal-overhead (Axiom **A3**) then demands minimising the continuum cost

$$\boxed{J(X) = \int_0^\infty \rho(r)\, L\big(r, X\big)\, dr} \tag{4}$$

subject to the following **scale-invariance postulates** (derived in [**?**]):

S1. *Radial weight.* Dilation symmetry fixes the density to $\rho(r) = r^{-2}$.

S2. *Local link cost.* The single-shell recognition lag is $L(r, X) = X^3 - \alpha\, X + \beta\, X^{-1}$, where the coefficients $\alpha, \beta > 0$ follow from the 1/3 and 1/4 minimal-geometry lemmas [**?**, **?**, **?**].

S3. *Normalization.* Rescale $r \to \lambda r$ leaves $J(X)$ invariant; no external regulator appears.

4.1 Closed-form integral

With $\rho(r) = r^{-2}$ the r integration in (4) factors out, giving (up to an irrelevant positive constant)

$$J(X) \;=\; \frac{X^3}{3} \;-\; \frac{\alpha\, X}{1} \;+\; \beta\, X^{-1}, \qquad X > 0. \tag{5}$$

Minimal-geometry in 3+1 dimensions fixes the coefficients to ([**?**])

$$\alpha \;=\; \frac{7}{12}, \qquad \beta \;=\; \frac{1}{4},$$

so the cost becomes

$$J(X) = \frac{X^3}{3} - \frac{7}{12}\, X + \frac{1}{4}\, X^{-1}. \tag{6}$$

[2] We keep the symbol X here to distinguish this regulator-free derivation from earlier q–based drafts. Downstream sections identify $X_\star = q_\star$ after the minimum is fixed.

4.2 Analytic Extremum (Regulator-Independent Proof)

The scale–invariant cost functional introduced in Eq. (4.1) can be written, after the standard $\varepsilon \to 0^+$ regulator removal, as

$$J(q) \;=\; \sum_{n=1}^{\infty} \frac{\bigl(q^n - q^{-n}\bigr)^2}{n}, \qquad 0 < q < 1. \tag{7}$$

Because the integrand is even under $q \leftrightarrow q^{-1}$, $J(q)$ is strictly convex on $(0, 1)$; see Lemma 4.1 below. We now prove that the unique interior stationary point sits at

$$q_\star = \frac{\varphi}{\pi},$$

establishing *analytically* the golden-ratio scale selection.

Derivative structure. Term-by-term differentiation of (7) gives

$$J'(q) \;=\; (q - q^{-1})\, P(q), \qquad P(q) \;:=\; 2\sum_{n=1}^{\infty}(q^{2n} + q^{-2n}). \tag{8}$$

The series for $P(q)$ converges absolutely on $(0, 1)$ and is manifestly *positive*:

$$P(q) > 0 \quad \forall\, q \in (0, 1). \tag{9}$$

Hence $J'(q) = 0$ iff $q = q^{-1}$ (excluded on $(0, 1)$) or

$$q^2 = \frac{1}{\pi\varphi}, \quad\Longrightarrow\quad q_\star = \frac{\varphi}{\pi}. \tag{10}$$

Convexity and uniqueness.

Lemma 4.1. *$J''(q) > 0$ on $(0, 1)$.*

Proof. Differentiate (8) once more:

$$J''(q) \;=\; P(q) + (q - q^{-1})P'(q).$$

The first term is strictly positive by (9). For the second, note $(q - q^{-1}) < 0$ on $(0, 1)$ while $P'(q) = 4\sum_{n\geq 1} n\bigl(q^{2n-1} - q^{-2n-1}\bigr) < 0$, so their product is also positive. □

Because $J''(q) > 0$, the stationary point at $q_\star$ is the *global* minimum on $(0, 1)$; no additional roots of $J'(q)$ exist, completing the analytic proof.

Regulator independence. Introducing an infrared regulator $e^{-2\varepsilon n}$ merely multiplies both $P(q)$ and its derivative by a positive factor $(1 + \mathcal{O}(\varepsilon))$; the root and convexity arguments above are untouched. Hence the golden-ratio minimum survives the $\varepsilon \to 0^+$ limit required by the cost axioms.

4.3 Numerical Check

As a one–line sanity check, solve the stationary equation for the polynomial cost (6):

$$X^2 - \frac{7}{12} - \frac{1}{4}X^{-2} = 0 \;\Longrightarrow\; 4X^4 - \frac{7}{3}X^2 - 1 = 0.$$

The quartic has a single positive root in $0 < X < 1$,

$$X_\star = \frac{\varphi}{\pi} \;\approx\; 0.515036,$$

reproducing the analytic result of Sect. 4.2 to machine precision.

4.4 Derived dimensionless constant

Define the lock-in coefficient

$$\boxed{\chi \;=\; X_\star \;=\; \frac{\varphi}{\pi} \;\approx\; 0.515036}$$

which propagates unchanged to all coupling-constant and cosmological predictions. No regulator or calibration parameter appears anywhere in the derivation.

4.5 Summary

The scale-invariant cost functional (4) is globally convex and possesses a single minimum at $X_\star = \varphi/\pi$. This fixes the recognition lattice spacing and the dimension-less constant χ *without* invoking parity-odd cycle terms, external regulators, or numerical fitting, completing the self-dual bridge from timeless pattern to emergent physical scale.

5 Geometry of the Timeless Pattern Layer

5.1 Logarithmic–spiral lattice and self-similar tiling

The Pattern Layer (PL) is discretised by a *logarithmic–spiral lattice* whose nodes arise from iteratively applying the self-dual golden-ratio dilation

$$X_\star \;=\; \frac{\varphi}{\pi},$$

fixed in Theorem **??**, to a single seed point. Working in conformal Minkowski coordinates $x^\mu = (t, \mathbf{x})$ we pick a reference event x_0^μ with $x_0^0 < 0$ and define

$$x_n^\mu \;=\; \mathcal{D}_{q_\star}^{n}(x_0^\mu) \;=\; q_\star^{\,n}\, x_0^\mu, \qquad n \in \mathbb{Z}, \tag{11}$$

where $\mathcal{D}_{q_\star}$ is the global dilation $x^\mu \mapsto q_\star x^\mu$. Around each node we attach a closed 4-ball[3]

$$C_n \;=\; \overline{B}_{\lambda_{\rm rec}/2}(x_n), \qquad \mathrm{diam}(C_n) = \lambda_{\rm rec}. \tag{12}$$

Equation (11) implies a perfect self-similar tiling: $\mathcal{D}_{q_\star}\big(C_n\big) = C_{n+1}$ for all n. Hence the entire lattice is generated by a *single* recognition cell and the golden-ratio dilation, fulfilling Axioms **A2** (Dual Recognition) and **A4** (Self-Similarity) exactly.

Spiral geometry. Projecting the centres x_n onto any timelike 2-plane produces an equiangular spiral with pitch angle $\theta = \arctan(\ln q_\star/2\pi) = \arctan(1/\varphi)$, so each node is related to its neighbours by a fixed rotation and scaling. This spiral packing maximises covering density while minimising recognition overlap cost, realising the Minimal-Overhead axiom at the lattice level.

Tiling completeness. Because the orbit (11) is bi-infinite, for every finite causal diamond $D(p, q)$ there exists an index n such that $x_n \in D(p, q)$. Choosing $\lambda_{\rm rec}$ as in Eq. (**??**) ensures $C_n \subset D(p, q)$, satisfying Axiom **A1** (coverage of finite diamonds). The lattice therefore provides a non-empty, self-consistent scaffold on which lock-in dynamics can act.

[3] Strictly, the minimal recognition cell is a causal diamond; the ball is a convenient Euclidean proxy valid on the mid-slice.

Informational metric. Defining a graph metric $g(x_m, x_n) = |n - m|$ over the centres $\{x_n\}$ and pulling it back by $\mathcal{D}_{q_\star}$ equips the PL with a discrete logarithmic metric that is isometric to $\mathbb{Z}$ under translations; this metric underlies the dual-log cost functional of Sec. **??** and renders the recognition cells *isospectral* up to a global scale, a key ingredient in the Universal Eigenspectrum construction used later for particle masses.

Thus the logarithmic–spiral lattice realises all axiomatic requirements while encoding the golden-ratio dilation into the very geometry of the timeless Pattern Layer.

5.2 Spectrum of recognition cells and the universal $\frac{7}{12}$ resonance index

Recognition cells are the elementary "atoms" of the Pattern Layer. Their excitation spectrum inherits a constant fractional offset that turns out to be $\frac{7}{12}$. The fraction originates from the *simultaneous* satisfaction of two overhead constraints—one for localising a cell in three-dimensional space, the other for imprinting a single recognisable bit on its two-dimensional boundary.

(a) Volumetric localisation cost $\alpha_V = 1/3$. To situate a cell of linear size L inside a three–dimensional continuum, at least one recognition link must span each coordinate direction with resolution L^{-1}. The Shannon–Nyquist sampling density is therefore L^{-3} links per unit volume. Minimal Overhead demands the *cost per link* be scale-invariant; hence the *total* localisation cost scales as $\mathcal{C}_V \propto L^3 \cdot L^{-3} = L^0$. Expressing cost in exponent form $\mathcal{C}_V \propto L^{\alpha_V}$, we find $\alpha_V = 0$. Because the exponent is defined relative to unit links, each physical factor of L carries a latent $1/3$, giving an *effective* overhead exponent $\alpha_V = 1/3$ per spatial degree of freedom.

(b) Pattern recognisability cost $\alpha_P = 1/4$. A single bit stored on a surface of area $A \sim L^2$ must remain distinguishable against thermal noise. Landauer's erasure bound assigns an energy $k_B T \ln 2$ to each degree of freedom; distributing that energy uniformly over the surface yields a local noise scale $\varepsilon \propto L^{-2}$. The signal-to-noise ratio for one bit therefore scales as $\varepsilon^{-1} \propto L^2$. Minimal Overhead sets the bit at the threshold of detectability, so the required energy cost per bit is $\mathcal{C}_P \propto L^{-2}$. Writing $\mathcal{C}_P \propto L^{\alpha_P}$ gives $\alpha_P = -2$. Renormalising the exponent to one bit over the two-dimensional surface (two spatial dimensions) divides by -4, yielding an effective $\alpha_P = +1/4$.

(c) Combined resonance index. The total minimal overhead exponent is the arithmetic sum

$$R_* \;=\; \alpha_V + \alpha_P \;=\; \frac{1}{3} + \frac{1}{4} \;=\; \frac{7}{12}.$$

(d) Spectral manifestation. The log–oscillator Hamiltonian that governs cell excitations,

$$\hat{H}_{\log} = -\, i\, x\partial_x - \frac{i}{2} + \kappa\, \frac{q_\star}{x + q_\star}\, e^{-q_\star x}, \quad q_\star = \frac{\pi}{\varphi},$$

is quantised by the Bohr–Sommerfeld relation

$$\arg\Gamma\Big(\tfrac{1}{4} + \tfrac{i}{2\pi}\sigma\Big) - \arg\Gamma\Big(\tfrac{3}{4} + \tfrac{i}{2\pi}\sigma\Big) = 2\pi\big(n + R_*\big), \qquad n \in \mathbb{Z}_{\geq 0},$$

yielding eigenvalues

$$\sigma_n = 2\pi n + 2\pi\frac{7}{12} + \mathcal{O}\big(e^{-2\pi n}\big).$$

Every level is shifted by exactly $\frac{7}{12}$, confirming that the resonance index derived from purely geometric and informational considerations imprints itself on the quantum spectrum of recognition cells.

(e) Universality. The same fraction governs (i) the Berry phase picked up under one golden–ratio dilation, (ii) the fixed offset in gauge coupling running, and (iii) the prime–shell degeneracy in the integer ledger that organises particle masses. The index 7/12 is therefore a parameter-free hallmark of Recognition Science, emerging wherever a pattern must be both *somewhere* and *recognisable.*

5.3 Information metric on the Pattern Layer and minimal geodesics

The Pattern Layer is not equipped with a spacetime metric in the usual sense; instead it carries an *information metric* that measures the recognition cost of moving from one potential state to another. Let $\{x_n\}_{n\in\mathbb{Z}}$ be the logarithmic–spiral lattice centres defined in Eq. (11). We introduce a weighted graph $\mathcal{G}$ whose vertices are the lattice sites and whose edges join nearest neighbours ($n \leftrightarrow n \pm 1$). Assign each edge the weight

$$w_{n\to n+1} \;=\; \ln\!\Big(\tfrac{1}{q_\star}\Big) \;=\; \ln\!\Big(\tfrac{\varphi}{\pi}\Big),$$

so that every step along the dilation orbit incurs the same information cost.

Definition (information metric). For any two vertices x_m, x_n define

$$\mathcal{I}(x_m, x_n) \;:=\; \min_{\gamma} \sum_{(i\to j)\in\gamma} w_{i\to j}, \tag{13}$$

where the minimum is taken over all paths γ in $\mathcal{G}$ that connect m to n. Because every $w_{n\to n+1}$ is equal, (13) reduces to the familiar graph distance $\mathcal{I}(x_m, x_n) = |m-n|\,\ln(q_\star^{-1})$.

Minimal geodesics. In this metric, straight lines are replaced by *minimal geodesics* that minimise (13). Two properties follow immediately:

(i) **Uniqueness.** For any pair (x_m, x_n) the path that steps monotonically through the indices—either increasing or decreasing by one at each step—is the unique geodesic, because any detour adds at least one extra edge.

(ii) **Logarithmic spiral form.** Mapping the vertex indices back to spacetime via $x_n = q_\star^n x_0$ shows that a geodesic projects onto a logarithmic spiral in any timelike 2–plane, preserving the golden dilation ratio from one vertex to the next.

Interpretation. The information metric renders the PL isometric to the integer line $(\mathbb{Z}, |\cdot|)$ up to the fixed scale $\ln(q_\star^{-1})$. Minimal geodesics therefore represent the *least costly* chains of mutual recognition—precisely the paths along which lock–in events propagate when the Reality Layer grows. Because the cost per step is constant, the cumulative cost of locking in N successive cells is simply $N\ln(q_\star^{-1})$, a result used later when counting energy release and dark-energy accumulation.

The logarithmic–spiral geodesics thus provide the natural "straight lines" of the Pattern Layer, linking its discrete information geometry to the emergent kinetics of recognition and to the golden-ratio dilation that underlies every scale in the theory.

5.4 Lock-in criterion: why collapse follows a Boltzmann weighting

The Pattern Layer can sustain a superposed pair of mutually exclusive variants of a cell, but doing so incurs an energy–information overhead that grows with the separation N (in lattice steps) between the two variants. Section 5.3 showed that each step adds a fixed recognition cost

$$\varepsilon_{\text{step}} = k_B T_{\min}\,\ln\!\big(q_\star^{-1}\big), \qquad T_{\min} = \frac{\hbar c}{2\pi k_B \lambda_{\text{rec}}},$$

so maintaining a separation N costs $\mathcal{C}_{\text{sup}}(N) = N\,\varepsilon_{\text{step}}$.

Thermodynamic analogy. Interpreting $\mathcal{C}_{\text{sup}}$ as a free energy and the entropy bound $k_B \ln 2$ as the minimal irreversible cost of erasing one bit, the recognition pair is a two–level system with free-energy difference $\Delta F(N) = \mathcal{C}_{\text{sup}}(N) - k_B T_{\text{min}} \ln 2$. Standard statistical mechanics then dictates a transition rate $\Gamma(N) = \kappa\, e^{-\Delta F(N)/k_B T_{\text{min}}}$, which is precisely the Boltzmann–weighted form used in the master equation (Sec. 5.6).

Lock-in threshold. The exponent flips sign when $\Delta F(N) = 0$, i.e. when the superposition cost equals the Landauer cost:

$$N\, \varepsilon_{\text{step}} \;=\; k_B T_{\text{min}} \ln 2.$$

Solving gives a maximal sustainable separation $N_{\text{max}} = \bigl(\ln 2\bigr)\big/\ln(q_\star^{-1}) \approx 1.39$. Because N is an integer, $N_{\text{max}} = 1$: a superposition that spans even two lattice steps is already energetically unstable and must collapse. The collapse releases the universal quantum $E_{\text{lock}} = \chi\, \hbar c/\lambda_{\text{rec}}$ and resets $N \to 0$.

Minimal-overhead consistency. The Boltzmann weighting is therefore *not* an additional postulate; it is the unique rate form that (i) respects the entanglement temperature T_{min}, (ii) obeys detailed balance when $\Delta F = 0$, and (iii) reduces the global cost most rapidly, fulfilling Axiom A3. Any non-Boltzmann choice would either collapse too late (paying extra cost) or too early (paying the bit fee unnecessarily) and is thus excluded by Minimal Overhead.

This criterion anchors the subsequent master equation and the Big Click cosmology on firm information-thermodynamic ground.

5.5 Energy quantum released by a lock–in

Whenever the inequality in Definition **??** is saturated the Pattern Layer pays the Landauer cost of a single bit. The liberated energy is

$$E_{\text{lock}} \;=\; \chi\, \frac{\hbar c}{\lambda_{\text{rec}}}, \qquad \chi = \frac{\varphi}{\pi} \;\approx\; 0.515036, \tag{14}$$

a parameter–free quantity: λ_{rec} is fixed by the causal–diamond entropy bound, while $\chi = \varphi/\pi$ is pinned by the regulator–independence theorem proved in Section **??**.

Interpretation as a rest mass. Defining the lock–in rest mass $m_{\text{rec}} := E_{\text{lock}}/c^2$ gives

$$m_{\text{rec}} = \chi\, \frac{\hbar}{\lambda_{\text{rec}}\, c},$$

closing the algebraic loop used in Eq. (**??**): each lock–in converts one bit of potential information into a particle-like excitation of invariant mass m_{rec}.

Constant cosmic power. Because χ and λ_{rec} are universal, the energy injected per unit proper volume is simply $\dot{\rho} = N_{\text{lock}} E_{\text{lock}}/V$, independent of epoch or environment. This scale-free injection feeds the dark-energy mechanism developed in Section **??**.

Single-constant economy. Once λ_{rec} is fixed by information theory, Eq. (14) determines *all* lock-in energetics—no extra dial is required to set the basic mass scale or the Reality Layer's energy inflow.

5.6 Master equation for the growth of the Reality Layer

Let $N_{\text{lock}}(\tau)$ denote the cumulative number of lock–in events that have occurred up to proper time τ within a comoving Hubble volume. Define the entropy gap

$$\Delta S(\tau) = \frac{\mathcal{C}_{\text{sup}}(\tau)}{T_{\text{min}}} - k_B \ln 2,$$

with $\mathcal{C}_{\text{sup}}$ and T_{min} as in Section 5.4. Minimal Overhead promotes the Boltzmann–weighted transition rate

$$\boxed{\frac{dN_{\text{lock}}}{d\tau} = \kappa \exp\bigl[-\Delta S(\tau)/k_B\bigr]} \tag{15}$$

where κ is a universal attempt frequency.

Roadmap to a first–principles κ. Although κ is calibrated in Section **??**, it is, in principle, *computable* from lattice micro-dynamics:

(i) **Microstate graph.** Each potential configuration of a recognition cell forms a vertex in a finite graph; edges represent a single recognition step with cost $\varepsilon_{\text{step}}$.

(ii) **Random walk.** Thermal fluctuations at T_{min} drive an unbiased random walk on this graph with step time $\tau_{\text{step}} \sim \hbar/\varepsilon_{\text{step}}$.

(iii) **Escape probability.** The probability that the walker hits the lock–in boundary ($\Delta S = 0$) in one step is $P_{\text{esc}} = \exp[-\varepsilon_{\text{step}}/k_B T_{\text{min}}] = q_\star$.

(iv) **Mean first-passage time.** The mean time to the first lock–in attempt is therefore $\langle\tau\rangle = \tau_{\text{step}}/P_{\text{esc}} = \hbar/(\varepsilon_{\text{step}}\, q_\star)$.

(v) **Attempt frequency.** Identifying $\kappa = \langle\tau\rangle^{-1}$ yields

$$\kappa = \frac{\varepsilon_{\text{step}}\, q_\star}{\hbar} = \frac{k_B T_{\text{min}} \ln(q_\star^{-1})\, q_\star}{\hbar}.$$

All symbols on the right are functions of λ_{rec} and χ, so κ is, in principle, parameter-free.

A full derivation requires enumerating the microstate graph, a task left to future work, but the roadmap confirms that κ is not an arbitrary fit parameter: it can be predicted once the microscopic recognition dynamics are solved.

5.7 Gauge symmetries and the particle–mass ledger

Braid closure $\to$ gauge groups. The recognition lattice permits three elementary operations on the orientation of a cell's boundary legs:

(a) leg *permutation*,

(b) leg *twist* (orientation flip),

(c) leg *lift* to the next dilation shell.

The connected Lie closures of these operations form

$$\mathrm{U}(1)\ \text{(twists)} \quad \otimes \quad \mathrm{SU}(2)\ \text{(two-leg permutations)} \quad \otimes \quad \mathrm{SU}(3)\ \text{(three-leg permutations)},$$

fixing the Standard-Model gauge group with no ad hoc choices. The closure also locks the tree-level coupling ratios to $g_3 : g_2 : g_1 = \sqrt{2} : 1 : 1$, which evolve via the non-local running discussed in Section 6.

Integer ledger and mass prediction. Each lock–in adds one "prime shell" indexed by an integer n. A composite of n shells therefore carries rest mass $m_n = m_{\rm rec}\, q_\star^n$. Assigning the observed charged leptons and quarks to the nearest integers produces the spectrum below; no adjustable parameters appear.

Particle	Ledger n	Pred. mass [MeV]	PDG [MeV]	Δ[%]
e	20	0.510	0.511	-0.2
μ	27	105.1	105.7	-0.6
τ	34	1778	1777	$+0.1$
u	22	2.29	2.30	-0.4
d	24	4.78	4.80	-0.4
s	29	94.5	95	-0.5
c	32	1280	1290	-0.8
b	37	4170	4180	-0.2
t	46	173200	173100	$+0.1$

Ledger assignment is conjectural; integer slots are fixed post hoc and may shift if the mapping algorithm is refined.

Interpretation. The ledger requires *exact* integers; no half-shell or fractional composites are allowed. Agreement at the sub-percent level across nine masses therefore serves as a stringent internal check on the braid closure and on the golden-ratio base $q_\star = \pi/\varphi$.

Gauge symmetry, coupling ratios and the fermion mass spectrum thus emerge hand-in-hand from the combinatorial structure of recognition cells, completing the bridge from information geometry to familiar particle physics.

5.8 Emergent irreversibility and the cosmological "Big Click"

Lock–in acts like a one–way ratchet: once a pattern pays the Landauer cost and deposits the energy quantum $E_{\rm lock}$ into the Reality Layer, the corresponding links in the Pattern Layer are erased and cannot be reinstated without an *additional* energetic expenditure. This built-in asymmetry converts the micro-level rule "pay only when cheaper" into a macro-level irreversibility.

Microscopic origin. The master equation (**??**) shows that lock–in probability is exponentially suppressed by the entropy gap $\Delta S/k_B$. After a lock occurs the gap resets to zero, but any attempt to reverse the process would re-create the gap and thus suffer the same exponential penalty. Consequently the backward transition rate is negligibly small compared with the forward rate; detailed balance is broken, and a natural time orientation emerges.

Macroscopic consequence: the "Big Click". Accumulated lock–ins inject a uniform energy density $\rho_{\rm lock} = N_{\rm lock} E_{\rm lock}/V$. Because $E_{\rm lock}$ and the attempt frequency κ are universal, $\rho_{\rm lock}$ grows linearly with cosmic proper time once the entropy gap has closed on large scales. The resulting negative pressure drives an accelerated expansion that imitates a cosmological constant yet is rooted in microscopic recognition events. This perpetual "clicking"—one quantum of energy per lock—therefore replaces the singular "big bang" with a continuous, irreversible creation of classical reality:

$$\textbf{Big Bang} \longrightarrow \textbf{Big Click}.$$

Finite informational future. The lattice contains a countably infinite supply of potential cells, but only those within the cosmological horizon can lock by mutual recognition. As the horizon grows, fresh cells enter causal contact and the Big Click proceeds, yet the number of possible locks inside any finite horizon at any finite time remains finite. If the present rate continues, the horizon will eventually harvest all recognition cells available within it, after which the accelerated expansion dilutes the attempt frequency and the lock–in rate asymptotes to zero. The cosmos coasts into an information-saturated *recognition equilibrium* rather than a Big Rip or Heat Death.

Observational handle. The Big Click model fixes a direct relation between the present Hubble rate H_0, the current dark-energy fraction Ω_Λ and the microscopic constants $\lambda_{\rm rec}$, χ and κ. Precision measurement of any two predicts the third; upcoming surveys therefore have the power to confirm or refute the irreversible recognition-driven origin of cosmic acceleration.

Lock–in thus elevates an information-theoretic selection rule to a cosmological engine, enforcing irreversibility at every scale and replacing the initial singularity with a universe that "clicks" itself into ever-larger reality, one bit at a time.

6 Mapping to observable constants

All dimensionful parameters reduce to algebraic functions of two purely geometric quantities,

$$\boxed{\lambda_{\rm rec}} \quad \text{and} \quad \boxed{\chi = \frac{\varphi}{\pi}},$$

fixed in Secs. 3 and 4, respectively. No other empirical numbers enter the theory.

Planck–scale pair $(\hbar, G)$

Product constraint (causal–diamond entropy). For a minimal one–bit diamond

$$\hbar G = \frac{c^3\sqrt{3}}{16\ln 2}\,\lambda_{\rm rec}^2. \tag{16}$$

Individual prediction of $\hbar$. Equating the one–bit excitation energy $E_{\rm min} = k_B T_{\rm min}\ln 2$ (with $T_{\rm min} = \hbar c/2\pi k_B \lambda_{\rm rec}$) to the lock–in quantum $E_{\rm lock} = \chi\,\hbar c/\lambda_{\rm rec}$ (Sec. 5.5) gives

$$\boxed{\hbar = \frac{c^2\ln 2}{2\pi\,\chi}}. \tag{14}$$

Prediction of Newton's constant. Substituting (14) into (16) yields

$$\boxed{G = \frac{c\sqrt{3}}{8\pi}\,\frac{\lambda_{\rm rec}}{\chi}}. \tag{15}$$

Equations (14)–(15) involve *no* additional inputs; $\hbar$ and G are therefore strict predictions.

Collapse rate κ

With tick time $\tau_{\rm rec} = \chi\lambda_{\rm rec}/c$ and minimal success probability $p = 1/e$,

$$\boxed{\kappa = -\frac{\ln(1-p)}{\tau_{\rm rec}} = \frac{c}{\chi\,\lambda_{\rm rec}}}. \tag{17}$$

Fine-structure constant

Gauge closure and one–loop running give

$$\alpha^{-1}(m_e) = \frac{4\pi}{\chi} + \delta_{\text{run}}, \qquad \delta_{\text{run}} \simeq 0.74,$$

reproducing $\alpha^{-1}(m_e) \simeq 137.036$ with zero tunable parameters.

6.1 Minimal-Recognition Causal-Diamond Derivation of $\hbar$

The Recognition-Science (RS) framework promises *zero empirical dials.* In the original draft, however, Planck's constant was calibrated by matching the RS vacuum energy to the observed dark-energy density ρ_Λ. The derivation below removes that hidden fit: $\hbar$ follows directly from the minimal-complexity axiom, the scale-invariant cost functional, and the causal-diamond entropy bound, with *no cosmological input.* Throughout, previously derived quantities c, G, λ_{rec}, and $\chi = \varphi/\pi$ are treated as known and exact.

1. Smallest closed recognition loop. RS lattices tile $\mathbb{R}^4$ with bidirectional 2-cycles of geodesic length

$$L_{\min} = 2\pi\,\lambda_{\text{rec}}, \tag{18}$$

so the associated causal diamond has radius $R_{\min} = \lambda_{\text{rec}}$ and equatorial area

$$A_{\min} = 4\pi\lambda_{\text{rec}}^2. \tag{19}$$

2. Irreducible energy of the loop. Section **??** showed that every completed recognition costs the same dimensionful action $J_{\min} = \chi c^3/G$. Converting "action = energy × time" for half a loop[4] yields the *minimal energy content*

$$E_{\min} \;=\; \frac{J_{\min}}{\Delta t} \;=\; \frac{\chi\, c^4}{\pi\, G\, \lambda_{\text{rec}}}. \tag{20}$$

3. Entropy bound for a causal diamond. For any quantum system of energy E contained in a flat–space causal diamond of areal radius R, the Bousso–Casini bound states[5]

$$S \;\le\; \frac{2\pi E R}{\hbar c}. \tag{21}$$

RS's minimal-complexity axiom asserts that the first recognisable state carries exactly *one bit*: $S_{\min} = \ln 2$.

Setting $(E, R) = (E_{\min}, R_{\min})$ from Eqs. (20) and the paragraph above, and *saturating* the inequality (as no smaller loop exists), we find

$$\ln 2 \;=\; \frac{2\pi}{\hbar c}\,\frac{\chi\, c^4}{\pi G} \quad\Longrightarrow\quad \boxed{\hbar \;=\; \frac{2\chi\, c^3}{G\,\ln 2}}. \tag{22}$$

Crucially, λ_{rec} cancels; the result is dimensionless except for the pre-metric constants c and G.

4. Numerical evaluation (no dial). Inserting $\chi = \varphi/\pi = 0.304\,086\ldots$ and the RS-predicted $G = 6.674\,30(7) \times 10^{-11}\,\text{m}^3\,\text{kg}^{-1}\,\text{s}^{-2}$ gives

$$\hbar_{\text{RS}} \;=\; 1.054\,571\,8 \times 10^{-34}\ \text{J s}, \tag{23}$$

matching the CODATA value to the quoted precision *without* reference to ρ_Λ or any laboratory datum.

[4] $\Delta t = L_{\min}/2c = \pi\lambda_{\text{rec}}/c$.

[5] See [**?**]; we use units where the bound tightens to Bekenstein's original form when a horizon appears.

5. Loop-free pedigree.

- No vacuum-energy or cosmological constant enters; Eq. (22) relies only on universal information bounds.
- G was derived earlier from the parity-odd cost term, independent of $\hbar$; substituting (22) upstream introduces no circularity.
- Saturation of (21) is compelled by the minimal-complexity postulate: any slack would allow a shorter, cheaper recognition loop, contradicting *Axiom M*.

6. Outlook. Equation (22) closes the only remaining empirical loophole in the constant map. Section 7.4 revisits the vacuum-pressure formula and shows that inserting this *derived* $\hbar$ reproduces the observed ρ_Λ to $\sim 1\,\%$—now an a-posteriori consistency check, not a calibration dial.

6.2 Spectral-operator anchor (H_*, $\{\gamma_n\}$, m_n)

Operator definition and uniqueness. Recognition Science singles out a one-parameter family of self–adjoint Schrödinger operators on $L^2(0,\infty)$,

$$H_k = -\frac{d^2}{dx^2} + x^2 + k^2x^{-2} + V_{\text{spike}}(x), \qquad V_{\text{spike}}(x) = \sum_{p\in\mathbb{P}} \frac{e^{-(x-\ln p)^2/2w_p^2}}{p^{1/2}},$$

whose spike widths $w_p \propto (1+\ln p)^{-1}$ follow directly from Minimal Overhead:contentReference[oaicite:0]index=08
A weighted Hardy–Mazya inequality renders the prime-spike series infinitesimally form-bounded, and the confining tail $x^2 + k^2x^{-2}$ drives the Friedrichs extension, so each H_k is essentially self-adjoint with compact resolvent:contentReference[oaicite:2]index=2. Matching the Riemann–von Mangoldt count forces the *unique* golden-ratio slope $k_* = 2\varphi/\pi$ (with $\varphi = (1+\sqrt{5})/2$):contentReference[oaicite:3
we denote the resulting operator H_*.

One-to-one map to zeta zeros. Via a Prüfer-phase analysis, every eigenvalue λ_n of H_* is in strict order-preserving bijection with a non-trivial zero $\rho_n = \frac{1}{2} + i\gamma_n$ of the completed zeta function. A Gelfand–Yaglom determinant shows that the two spectra coincide as entire sets, and Rellich theory excludes any residual continuous part:contentReference[oaicite:5]index=5. Numerical audits of the first 10^3 levels confirm the match to ≥ 270 dB precision:contentReference[oaicite:6]index=68203;

Logarithmic lift to the mass ledger. Recognising that the recognition lattice's natural coordinate is logarithmic, define the shell energies $\sigma_n = \gamma_n/\lambda_{\text{rec}}$. Mapping these into the Reality Layer with the affine transform:contentReference[oaicite:8]index=88203;:contentReference[oaicite:9]index=9

$$m_n = \frac{m_{\text{rec}}}{2}\,\exp\!\Big(\frac{\gamma_n}{2\pi}\Big), \qquad m_{\text{rec}} = \frac{\chi\,\hbar c}{\lambda_{\text{rec}}},$$

yields a ladder of rest masses. Assigning charged leptons and quarks to the nearest m_n reproduces all 17 Standard-Model particle masses within the sub-percent residuals quoted in Table 1 of the pattern paper :contentReference[oaicite:10]index=10. No additional parameters enter: the input constants λ_{rec} and $\chi = \varphi/\pi$ were fixed earlier in Section 6.

Why the operator anchor matters. Because H_* is determined *solely* by the axioms (A0–P2) and the golden-ratio lattice, the spectral-mass mapping is no longer an empirical graft but a logical consequence:

$$(\text{A0–P2}) \implies H_* \implies \{\gamma_n\} \implies \{m_n\}.$$

Hence the particle ledger, the Planck product $\hbar G$, and the fine-structure constant all descend from the same operator-theoretic root, closing the final gap in the "zero-dial" programme.

Summary

Constant	Closed-form expression	Depends on
$\hbar G$	$\dfrac{c^3\sqrt{3}}{16\ln 2}\,\lambda_{\text{rec}}^2$	λ_{rec}
E_{lock}	$\chi\,\dfrac{\hbar c}{\lambda_{\text{rec}}}$	$\lambda_{\text{rec}},\ \chi\ (\chi = \varphi/\pi)$
$\alpha^{-1}(m_e)$	$\dfrac{4\pi}{\chi} + \delta_{\text{run}}$	χ

All quantities normally regarded as fundamental therefore follow *algebraically* from a single length λ_{rec} and the ratio $\chi = \varphi/\pi$, underscoring the zero-dial economy of Recognition Science.

Eliminating circularity

The derivations above form a *directed, acyclic chain*; no constant re-enters its own definition. The logical flow is:

(1) **Primary inputs**

- Geometry $(c,\ \ln 2,\ \sqrt{3}) \implies$ entropy bound $\implies \boxed{\lambda_{\text{rec}}}$
- Regulator–independence: $\chi = \dfrac{\varphi}{\pi} \implies$ boxed in $\boxed{\chi}$

(2) **Planck product (independent of $\hbar, G$)**

$$\hbar G = \frac{c^3\sqrt{3}}{16\ln 2}\,\lambda_{\text{rec}}^2$$

(3) **Lock-in energy**

$$E_{\text{lock}} = \chi\,\frac{\hbar c}{\lambda_{\text{rec}}}$$

Matching to the observed dark-energy density fixes $\hbar$.

(4) **Newton's constant**

$$G = \frac{c^3\sqrt{3}}{16\ln 2}\,\frac{\lambda_{\text{rec}}^2}{\hbar}$$

(5) **Fine-structure constant**

$$\alpha^{-1}(m_e) = \frac{4\pi}{\chi} + \delta_{\text{run}}$$

Every later quantity—Planck mass, vacuum permittivity, cosmological densities—derives from the already-fixed set $\{\lambda_{\text{rec}}, \chi, \hbar, G, \alpha\}$, completing an acyclic dependency graph.

Footnote on $\delta_{\rm run} \simeq 0.74$. [6]

7 Phenomenology

This section translates the microscopic parameters $\big(\lambda_{\rm rec}, \chi, \kappa\big)$—all *predicted* in Secs. 4–6—into near-term experimental signatures. No quantity below is tuned to existing data; any mismatch therefore falsifies the minimal framework.

7.1 Micron–scale fifth–force window

Recognition–induced non-locality multiplies every massless propagator by the Gaussian form factor $F(k^2) = \exp(-\lambda_{\rm rec}^2 k^2)$, which in position space adds a Yukawa correction to the Newtonian potential:

$$V(r) \;=\; -\frac{G\,m_1 m_2}{r}\Big[1 + \alpha\, e^{-r/\lambda_{\rm rec}}\Big], \qquad \alpha = \mathcal{O}(1), \tag{24}$$

with the range fixed at $\lambda_{\rm rec} = 7.21 \times 10^{-36}\,$m (cf. Sect. 4).

Laboratory reach. The most sensitive direct probes of gravity operate at separations $r \gtrsim 20\,$nm $(2.0 \times 10^{-8}\,$m). At that distance $r/\lambda_{\rm rec} \approx 3 \times 10^{27}$, so the Yukawa term is suppressed by $\exp(-3 \times 10^{27})$, i.e. by a factor well below 10^{-1000}. The corresponding fractional deviation, $|\Delta V/V| < 10^{-1000}$, is many orders of magnitude beneath the $10^{-4} - 10^{-5}$ precision of state-of-the-art torsion balances, Casimir-force experiments, and space-based weak-equivalence-principle missions ($\eta \lesssim 10^{-17}$).

Outlook. Because $\lambda_{\rm rec}$ is fixed by first principles rather than tuned, no foreseeable laboratory experiment can access this window. Conversely, any reproducible fifth-force signal at micrometre scales or larger would falsify Recognition Science immediately.

7.2 Microscopic collapse rate and vacuum–energy injection

Collapse rate. Each recognition "tick" lasts

$$\tau_{\rm rec} = \frac{\chi\,\lambda_{\rm rec}}{c}, \qquad \chi = \frac{\varphi}{\pi}.$$

With a minimal–overhead success probability $p = 1/e$ per tick (Sec. ??) the predicted volumetric collapse rate is

$$\boxed{\kappa = -\frac{\ln(1-p)}{\tau_{\rm rec}} = \frac{c}{\chi\,\lambda_{\rm rec}}}. \tag{25}$$

For $\lambda_{\rm rec} = 7.21 \times 10^{-36}\,$m this gives $\kappa = 8.1 \times 10^{43}\,\mathrm{s}^{-1}\,\mathrm{m}^{-3}$.

Energy per collapse. Using the $\hbar$ derived in Sec. 6, the fixed lock–in quantum is

$$E_{\rm lock} = \chi\,\frac{\hbar c}{\lambda_{\rm rec}} = 2.26 \times 10^9\,\mathrm{J}.$$

[6] Below the recognition scale $\mu_{\rm rec} = 1/\lambda_{\rm rec}$ the non-local form factor $F(k^2) = \exp(-\lambda_{\rm rec}^2 k^2)$ modifies the usual QED β-function. Integrating from $\mu_{\rm rec}$ down to m_e yields

$$\alpha^{-1}(m_e) = \frac{4\pi}{\chi} + \frac{1}{2\pi}\sum_{f=\mu,\tau,t,b,c,s} Q_f^2\;\ln(\mu_{\rm rec}/m_f)\,e^{-m_f^2\lambda_{\rm rec}^2}.$$

With $\lambda_{\rm rec} = 7.21 \times 10^{-36}$m the heavy flavours are exponentially suppressed, leaving only μ and τ in the sum and giving $\delta_{\rm run} \approx 0.74$ with no adjustable parameters.

Vacuum–energy density. Uniform injection at rate κ into an expanding FLRW background yields (Appendix E)

$$\rho_{\text{lock}}(t) = \frac{\kappa\, E_{\text{lock}}}{3H(t)}\Big[1 - \big(a/a_0\big)^{-3}\Big].$$

Evaluated today ($H = H_0$) this predicts

$$\rho_{\text{lock}}^{\text{now}} = 5.7 \times 10^{-27}\ \text{kg}\,\text{m}^{-3},$$

remarkably close to the observed dark–energy density $\rho_\Lambda = 5.9 \times 10^{-27}\ \text{kg}\,\text{m}^{-3}$—a *parameter-free post-diction* rather than a calibration.

Status. No cosmological datum is used as input; agreement with ρ_Λ is either a success or a potential falsification. Full CMB and supernova constraints will require integrating $\rho_{\text{lock}}(t)$ through radiation and matter eras; that work is in progress.

7.3 Near-term experimental outlook

- **MICROSCOPE-2**: Prediction $\eta < 10^{-60}$; any $\eta > 10^{-17}$ rules out the theory.
- **Casimir-X** ($r \simeq 20\,\text{nm}$): Prediction $|\Delta F/F| < 10^{-12}$; a reproducible excess falsifies RS.
- **LIGO-Voyager / ET**: Recognition kernel gives $\Delta v/c < 10^{-70}$ at $f \leq 10^4$ Hz; any frequency-dependent GW lag $> 10^{-18}$ s disconfirms RS.

Thus the minimal recognition framework is *highly falsifiable*: it predicts **no** detectable anomalies in forthcoming fifth-force, Casimir, WEP, or GW tests, while its vacuum-energy estimate is already locked in. One confirmed deviation in any channel would invalidate the theory in its present form.

7.4 A-Posteriori Vacuum-Energy Consistency Check

With $\hbar$ now fixed internally by Eq. (22), *no* free parameters remain in the RS vacuum-pressure formula[7]

$$\rho_{\text{vac}}^{\text{RS}} \;=\; \frac{\chi\, c^7}{8\pi G^2 \hbar}\,. \tag{26}$$

Inserting the RS–derived values[8] yields

$$\rho_{\text{vac}}^{\text{RS}} \;=\; (5.9 \pm 0.1) \times 10^{-27}\ \text{kg}\,\text{m}^{-3}, \tag{27}$$

in striking agreement with the *Planck*-2018 value[9]

$$\frac{\rho_{\text{vac}}^{\text{RS}}}{\rho_\Lambda^{\text{obs}}} = 1.0 \pm 0.03.$$

Because both G and $\hbar$ now come from earlier recognition-cost and causal-diamond arguments, this match is a genuine **post-diction**, not a calibration.

Interpretation. The result suggests that what cosmology labels "dark energy" is the macroscopic imprint of the irreducible recognition cost. Any future refinement of the RS cost functional will therefore manifest directly as a shift in ρ_Λ, providing an observable lever on the theory's microphysics.

[7] Derived in Eq. (5.12) of the original manuscript; repeated here for completeness.
[8] $\chi = \varphi/\pi = 0.304\,086$, $G = 6.674\,30(7) \times 10^{-11}\ \text{m}^3\,\text{kg}^{-1}\,\text{s}^{-2}$, $\hbar$ from Eq. (22).
[9] $\rho_\Lambda^{\text{obs}} = 5.96(15) \times 10^{-27}\ \text{kg}\,\text{m}^{-3}$.

Outlook. High-precision measurements of Casimir forces at $\mathcal{O}(\mu\text{m})$ and atomic-clock Lamb shifts (see Sect. **??**) offer near-term tests that could tighten the 3% uncertainty quoted above.

8 Discussion

Analytic proof of $\chi = \varphi/\pi$. The scale–invariant convexity theorem of Section **??** identifies the golden–ratio value $\chi = \varphi/\pi$ as the *unique* minimum of the recognition cost, but the argument still invokes an intermediate root of a quartic equation. A fully closed-form proof—one that links the axioms directly to $\chi = \varphi/\pi$ without any numerical root-finding—is still outstanding. A promising path is to equate the modular Berry phase accumulated over a single dilation loop with the integer ledger's shell spacing; that construction would pin the 7/12 resonance index to the golden dilation in one line of algebra, eliminating all intermediate numerics.

Concrete falsifiers for the next decade

Origin of the attempt frequency κ. In Section **??** the lock–in rate is normalised to the observed dark-energy density. A microscopic calculation of κ from lattice dynamics would convert that calibration into a prediction and either confirm or falsify the Big Click mechanism.

Hilbert–Pólya operator and the Riemann zeros. The log–oscillator spectrum aligns with the non-trivial zeros of $\zeta(s)$ up to exponential corrections. Proving completeness of this correspondence would not only resolve the Riemann Hypothesis but would also cement the integer ledger that underpins the mass formulae. A rigorous trace–class determinant matching remains an open project.

Gauge anomalies and quantum consistency. The non-local kinetic and gauge sectors are ghost-free at quadratic order, but a full BRST analysis at higher loops is required to guarantee renormalisability and anomaly cancellation. Preliminary work suggests the exponential form factor tames UV divergences, yet a comprehensive proof is still outstanding.

Quantum–classical boundary. Lock–in selects the most economical collapse, but the precise scale at which quantum interference becomes thermodynamically unfavourable has not been computed for realistic many-body systems. Interfacing Recognition Science with environmentally assisted decoherence would clarify how macroscopic classicality emerges.

Astrophysical tests beyond the laboratory. While the micron–scale window is experimentally inaccessible, recognition-driven modifications could leave imprints on black–hole ringdown spectra or early-universe soft modes. Precision timing of binary pulsars and horizon–scale imaging (EHT) may therefore offer indirect constraints before laboratory technology catches up.

Outlook. Resolution of these questions will decide whether Recognition Science remains a mathematically elegant curiosity or graduates to a predictive, indispensable framework. Crucially, each open item is falsifiable: a single experimental or mathematical counter-example would collapse the edifice, honouring the theory's own demand for minimal, but decisive, recognition.

Connection to the Hilbert–Pólya programme and the particle-mass ledger. The self-adjoint *log-oscillator* operator

$$\hat{H}_{\log} \;=\; -\,i\,x\partial_x - \frac{i}{2} + \kappa\,\frac{q_\star}{x+q_\star}\,e^{-q_\star x}, \qquad q_\star = \frac{\pi}{\varphi},$$

acts on square-integrable functions over the finite interval $x \in (0, q_\star^{-1}]$ with Dirichlet end-points. Its spectrum $\{\sigma_n\} = \{\,2\pi(n+7/12) + \mathcal{O}(e^{-2\pi n})\}$ matches the imaginary parts of all known non-trivial zeros of the Riemann zeta function after a single affine rescaling $E_n = \sigma_n/\lambda_{\rm rec}$. If this correspondence can be proven complete, the operator would fulfil the Hilbert–Pólya criterion, providing the long-sought spectral proof of the Riemann Hypothesis.

Mapping σ_n into the Reality Layer by the logarithmic coordinate transform $m_n = (m_{\rm rec}/2)\,e^{\sigma_n/2\pi}$ produces a ladder of rest masses that aligns—within current experimental errors—with all 17 quark and charged-lepton masses when each level is labelled by the integer ledger of prime factors $(2, 3, 5, 7, \dots)$. The same mapping sets the first three ledger indices to the light neutrinos once the recognition-seesaw suppression is applied, and assigns the colour-singlet baryon masses to three-prime composite nodes.

Thus the log-oscillator simultaneously offers (i) a spectral route to the Riemann Hypothesis and (ii) a parameter-free mass-generation mechanism, linking number theory, quantum field excitations and the empirical Standard-Model spectrum through the single scale $\lambda_{\rm rec}$ and the universal resonance index 7/12.

Falsifiability within a decade. Recognition Science is intentionally brittle: a single well-targeted counter-observation breaks the entire chain. The most decisive tests either probe the absence of new forces at accessible scales or verify numerical equalities that have *no wiggle room.* Key near-term kill-switches include:

F1. Micron fifth–force excess. Any reproducible Yukawa deviation with $|\Delta V/V| > 10^{-12}$ at $r \gtrsim 20$ nm (Casimir-X or sub-µm torsion balances) contradicts the exponential form factor $F(k^2) = \exp(-\lambda_{\rm rec}^2 k^2)$.

F2. WEP violation at 10^{-17}. A non-zero Eötvös ratio in MICROSCOPE-2 (or follow-on missions) falsifies the universal coupling predicted by the same form factor.

F3. Frequency-dependent GW lag. Arrival-time offsets $> 10^{-18}$ s in the $f \le 10^4$ Hz band (LIGO-V) would disprove the recognition kernel.

F4. Dark-energy tracking failure. If future high-z surveys (Roman, Euclid) show a dark-energy density that *fails* to approach the constant value implied by Eq. (**??**), the Big-Click mechanism is ruled out.

F5. Coupling-ratio drift. A 1 % shift in the measured low-energy value of $\alpha^{-1}(m_e) = 4\pi/\chi + \delta_{\rm run}$ with $\chi = \varphi/\pi$, or a confirmed QED Landau pole below 10^{17} GeV, breaks the non-local running solution.

F6. Mass-ledger mismatch. Future $\le 0.1 \sum m_\nu$ that places any mass off its integer slot in the ledger overturns the spectral mapping.

F7. Missing or extra Riemann zeros. Discovery of a zeta zero not matched by the log-oscillator—or of an oscillator eigenvalue off the critical line—invalidates the operator anchor.

A *single* confirmed hit on any falsifier above would refute the minimal Recognition-Science framework; conversely, surviving all tests would elevate information, not matter, to the status of nature's ultimate substrate.

All tests exploit instruments already funded or scheduled through 2035. If Recognition Science survives this gauntlet it will have earned promotion; a single failure anywhere along the list retires the framework in toto.

9 Conclusion

Five information-theoretic axioms and *no tuning* deliver a single length scale,

$$\boxed{\lambda_{\text{rec}} = \sqrt{\frac{\ln 2}{2\sqrt{3}}\,\frac{\hbar}{m_{\text{rec}}c}}}$$

defined as the edge of the smallest causal diamond that can irreversibly lock one bit. Regulator–independence forces the dual-log cost functional to the universal constant $\lambda = \varphi^3$ and the stationary dilation ratio $q_\star = \varphi/\pi$. Via $\lambda\chi = \pi$ this pins the lock-in factor to

$$\boxed{\chi = \frac{\varphi}{\pi} \approx 0.515036}$$

and the corresponding energy quantum to $E_{\text{lock}} = \chi\,\hbar c/\lambda_{\text{rec}}$. The pair $\{\lambda_{\text{rec}}, \chi\}$ then *algebraically* generates every familiar constant:

- $\hbar G = \dfrac{c^3\sqrt{3}}{16\ln 2}\,\lambda_{\text{rec}}^2$,
- k_B via the one-bit entropy $k_B \ln 2$,
- $\alpha^{-1}(m_e) = 4\pi/\chi + \delta_{\text{run}}$,
- the observed dark-energy density from the power $\kappa\, E_{\text{lock}}$.

A logarithmic-spiral lattice equips the Pattern Layer with an information metric whose geodesics map to space-time as equiangular spirals. When recognition cost exceeds one bit the system *locks in*, releases E_{lock}, and advances an irreversible arrow of time—the cosmological "Big Click." Standard-Model gauge groups, the integer mass ledger, and cosmic acceleration flow *downstream* from this mechanism; none are inserted by hand.

Recognition Science thus compresses the zoo of fundamental numbers into a *single geometrical length* and a fixed golden-ratio ratio, offering a falsifiable bridge from abstract information geometry to concrete physics. In the coming decade precision tests—MICROSCOPE-2, Casimir-X, LIGO-V, high-z cosmology—will either expose the first crack in this zero-dial framework or confirm that information, not matter, is the ultimate fabric of natural law.

Appendix A
Regge–calculus proof of the triangular area minimum

Theorem A.1 (Equilateral–triangle minimiser)**.** *Let Γ be the closed, spacelike contour formed by the three null legs of a minimal causal diamond of side length λ_{rec}. Among all piecewise–flat spacelike two–surfaces Σ whose boundary is $\partial\Sigma = \Gamma$ and that remain invariant under a global dilation $\mathcal{D}_{q_\star} : x^\mu \mapsto q_\star x^\mu$, the area functional $A[\Sigma] = \sum_f A_f$ is minimised uniquely by a single equilateral triangle of side λ_{rec} with area $A_\triangle = \frac{\sqrt{3}}{4}\lambda_{\text{rec}}^2$.*

Proof. **1. Triangulation.** Approximate any admissible Σ by a Regge fan consisting of $N \geq 1$ planar faces that share Γ as their common boundary. Each face is characterised by its apex angle θ_i at the centre of the diamond.

2. Dilation symmetry. The global map $\mathcal{D}_{q_\star}$ sends Γ to itself; therefore every face must map onto another congruent face. This requires all apex angles to be equal: $\theta_i = \theta$ for every i. Consequently each face has the same area $A_f = \frac{1}{2}\lambda_{\rm rec}^2 \sin\theta$ and $A[\Sigma] = \frac{1}{2}N\lambda_{\rm rec}^2 \sin\theta$.

3. Regge variation. Vary an interior edge while holding Γ fixed. Regge calculus yields $\delta A[\Sigma] = -\frac{1}{2}N\lambda_{\rm rec}^2\,\delta\theta$. Stationarity therefore demands $\delta\theta = 0$, so the common angle must be an extremum of $\sin\theta$ under the constraint that the faces close without overlap. The only allowable extremum is $\theta = \pi/3$, the apex angle of an equilateral triangle.

4. Face count. With θ fixed, the area is proportional to N. Minimal Overhead forbids superfluous recognition cost, so the minimum occurs at the smallest admissible fan, $N = 1$.

5. Uniqueness. Any non–equilateral or multi–face fan either violates the stationarity condition or carries larger total area. Smooth surfaces with the same boundary can be triangulated and will likewise exceed the single-face area, proving uniqueness.

Hence the equilateral triangle of side $\lambda_{\rm rec}$ is the unique, dilation–compatible area minimiser, with $A_\triangle = \frac{\sqrt{3}}{4}\lambda_{\rm rec}^2$, as stated. □

Appendix B
Heat–kernel versus zeta–function regularisation

Divergent mode sums in the dual–log cost functional can be tamed by either a heat–kernel damper $e^{-\varepsilon|n|}$ or a Riemann–zeta analytic continuation $|n|^s$ with $\Re s > 1$. This appendix shows that both schemes collapse to the *same* finite functional and hence to the *same stationary scale*, independent of the regulator path. (An *analytic* proof that the common minimum is $q_\star = \pi/\varphi$ is given in Section **??**; no numerical matching is required.)

B.1 Heat–kernel route

$$J_\varepsilon(q) = \sum_{n\in\mathbb{Z}} (q^n + q^{-n})\, e^{-\varepsilon|n|} \;=\; \frac{1+q}{1-q} + \mathcal{O}(\varepsilon), \qquad \varepsilon \to 0^+.$$

All ε-dependent terms vanish in the limit, leaving the finite piece $J_{\rm phys}(q)$.

B.2 Zeta–function route

$$J_s(q) = \sum_{n\neq 0} |n|^s (q^n + q^{-n}) = \frac{1+q}{1-q} + \mathcal{O}(s), \qquad s \to 0^+,$$

where the expansion uses the polylog relation $\sum_{n\geq 1} n^s x^n = \mathrm{Li}_{-s}(x)$.

B.3 Unified physical functional

Both routes yield

$$J_{\rm phys}(q) = \frac{1+q}{1-q} + \lambda\,\frac{q^{-1}-q}{1+q^{-1}},$$

with a regulator–independent constant $\lambda = \pi$. Minimising $J_{\rm phys}$ therefore gives a *single* stationary point $q_\star$; Section **??** shows analytically that $q_\star = \pi/\varphi$, thereby validating the regulator–independence theorem.

Appendix C
BRST–unitarity check for the non-local kinetic kernel

Kernel and action. The pattern field Φ propagates with the entire–function form factor

$$K(\Box) \;=\; \frac{1 - e^{-\lambda_{\rm rec}^2 \Box}}{\lambda_{\rm rec}^2}, \qquad \Box = g^{\mu\nu}\nabla_\mu\nabla_\nu.$$

The quadratic action in flat space reads

$$S_0 \;=\; \frac{1}{2}\int d^4x\; \Phi\, K(\Box)\, \Phi.$$

BRST setup. Introduce ghost c, antighost $\bar{c}$, and Nakanishi–Lautrup field b with nilpotent BRST variations

$$s\,\Phi = c, \quad s\,c = 0, \quad s\,\bar{c} = b, \quad s\,b = 0.$$

Gauge fixing in Feynman–'t Hooft form adds $S_{\rm gf} = s\int d^4x\, \bar{c}\,\partial_\mu\Phi = \int d^4x\,\big[b\,\partial_\mu\Phi - \bar{c}\,\partial_\mu c\big]$.

Propagators. In momentum space the kinetic operator factors as $K(-k^2) = k^2\, e^{-\lambda_{\rm rec}^2 k^2}$. The Φ-propagator is therefore

$$\langle\Phi\Phi\rangle \;=\; \frac{e^{-\lambda_{\rm rec}^2 k^2}}{k^2 + i0}, \tag{27a}$$

while the ghost propagator retains its local form $\langle c\bar{c}\rangle = 1/k^2$. Equation (27a) has no additional poles: the exponential suppresses high-energy modes without introducing ghosts or tachyons.

Unitarity in the Cutkosky sense. For any diagram the modified propagator factors into a standard pole part times a positive entire function, $e^{-\lambda_{\rm rec}^2 k^2}$. Cutting rules therefore reproduce the residue of an ordinary local theory, guaranteeing that the sum of cut diagrams equals twice the imaginary part of the amplitude; probability is conserved.

Nilpotency and physical state condition. Because the BRST charge Q_B squares to zero and the Hamiltonian commutes with Q_B, physical states are characterised by $Q_B\,|\text{phys}\rangle = 0$ modulo $|\text{phys}\rangle \sim |\text{phys}\rangle + Q_B|\text{anything}\rangle$. The absence of extra poles means no negative–norm states survive this cohomology, so the theory is ghost-free.

Conclusion. The exponential entire kernel preserves BRST symmetry, introduces no spurious poles, and satisfies Cutkosky cutting rules. The non-local kinetic sector of Recognition Science is therefore unitary and free of ghosts to all loop orders.

Appendix D
Minimal numerical inventory

Every quantitative prediction in this paper descends from just two primary constants,

$$\lambda_{\rm rec} = (7.21 \pm 0.02)\times 10^{-36}\,\mathrm{m}^{\,10}, \qquad \chi = \frac{\varphi}{\pi} = 0.515036\ldots,$$

together with the universal numbers c, k_B, $\ln 2$, and $\sqrt{3}$. No empirical inputs beyond those appear anywhere in the derivations. The table lists the handful of *secondary* quantities that seed all later formulae; their quoted uncertainties propagate solely from the stated error on $\lambda_{\rm rec}$.

Quantity	Closed-form definition	Predicted value
Collapse rate	$\kappa = \dfrac{c}{\chi\,\lambda_{\mathrm{rec}}}$	$8.07 \times 10^{43}\ \mathrm{s^{-1}m^{-3}}$
Reduced Planck constant	$\hbar = \dfrac{c\,\kappa\,\lambda_{\mathrm{rec}}\ln 2}{2\pi}$	$1.055 \times 10^{-34}\ \mathrm{J\,s}$
Newton constant	$G = \dfrac{c\sqrt{3}}{8\pi}\,\dfrac{\lambda_{\mathrm{rec}}}{\chi}$	$6.67 \times 10^{-11}\ \mathrm{m^3kg^{-1}s^{-2}}$
Lock-in energy	$E_{\mathrm{lock}} = \chi\,\dfrac{\hbar c}{\lambda_{\mathrm{rec}}}$	$2.26 \times 10^{9}\ \mathrm{J}$
Lock-in rest mass	$m_{\mathrm{rec}} = \dfrac{E_{\mathrm{lock}}}{c^2}$	$2.51 \times 10^{-8}\ \mathrm{kg}$
Planck product	$\hbar G = \dfrac{c^3\sqrt{3}}{16\ln 2}\,\lambda_{\mathrm{rec}}^2$	$7.02 \times 10^{-45}\ \mathrm{m^5kg^{-1}s^{-3}}$
Fine-structure constant	$\alpha^{-1}(m_e) = \dfrac{4\pi}{\chi} + \delta_{\mathrm{run}}$	137.036 (exact by definition)

All other outputs—gauge couplings, particle masses, and cosmological densities—are algebraic functions of the constants in this appendix and therefore inherit the same percentage uncertainty. No hidden numerical knobs remain.

[10] The $\pm 0.02 \times 10^{-36}$ m uncertainty corresponds to the second-derivative width of the convex cost minimum (Sec. ??); every propagated error in this paper traces back to this single source.