Entropy

Volume 5: The Cosmological Budget

Edition 2.5

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Edition 2.5 note

This volume restores the March 2026 text of *The Cosmological Budget* in its original voice and structure wherever a claim survived the October 2026 second edition, and uses the second edition's substance throughout. Both earlier editions remain intact and unchanged; this text sits beside them. It follows the expanded six-chapter branch, as the second edition did; the separate FINISHED coda is not included.

Four rules govern every line:

- **No withdrawn claim returns.** Where a March sentence carried a claim the second edition withdrew, it is cut, rewritten to the second edition's substance, or quoted only to mark its withdrawal. Each correction points to its row in the correction ledger (V5-L).
- **No analogy becomes evidence.** Analogies are tagged Analogical and mapped term by term in the two analogy tables. Hypotheses are tagged Speculative; testable is not the same as supported.
- **Results keep their settings.** A mathematical construction, a fitted cosmology, a semiclassical prediction and a laboratory result each keep the conditions under which they hold. None is promoted to an unconditional fact about the universe or about relationships.
- **Absence claims are scoped.** Where this volume says something is not established, it means not established by the sources reviewed here, not that no research anywhere bears on it.

No study, protocol or experiment is proposed. Where a chapter says what a test would need, it restates the second edition. This volume makes no claim about the existence or absence of an afterlife, cosmic purpose or personal survival, and offers no medical or longevity advice.

Epistemic tiers

The framework uses four epistemic tiers. A tier is a label for evidence stated next to the claim; the label itself is not evidence.

- **Established:** experimentally verified or mathematically proven, within stated conditions.
- **Supported:** substantial evidence for the stated scope, short of Established.
- **Analogical:** a structural mapping between a physical result and a relational pattern. The physical side keeps its own standing within its stated scope. The mapping can raise questions and help explain, but on its own it does not validate the proposed application; it moves only by the promotion route stated with it.
- **Speculative:** a proposal without independent evidence, for which no conflict with known physics has yet been identified. That is not a proof of consistency.

Collapsing tiers is the framework's cardinal epistemic sin: presenting a Supported claim at Established confidence, a Speculative claim as Supported, or an Analogical mapping as validation of its application.

Conventions and provenance

Reference labels are the second edition's: group C for Chapters 2 and 3, group I for Chapters 4 and 5, and the I-CALC notes for the calculations behind corrected figures, all listed at the end of the volume. Ledger references (V5-L01 to V5-L89) point to the correction ledger. The founding line is mapped in the Volume 1 analogy table. That analogy table is not repeated here.

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Chapter 1: The Problem

The Ledger at Its Widest

> *“Love reduces the entropy of the system and spends more than it saves.” — The Principal, March 17, 2026*

[Analogical; see the Volume 1 analogy table]

Status: This chapter frames the cosmological questions. Entropy estimates and horizon results have specified boundaries and model assumptions. Their application to a relational account remains a proposal, not a measured universal budget (V5-L05).

1 The question

Volumes 1 through 4 worked upward, each at its own resolution: the physical accounts, the body, the history, the gradient. Their revised argument keeps those questions while withdrawing a common physical price for relational value and a universal efficiency ranking.

This volume works outward. The March chapter said the ledger the framework describes is the universe's entropy budget, and set out to open it at its widest (V5-L01). The corrected question is narrower and harder: what does cosmology actually constrain about the systems in which relationships occur? How do an entropy inventory, an information bound, an accessible resource and an uncertain cosmic future differ? The scale grows; the need to define what is being counted does not shrink.

The ledger remains a useful image for asking what an activity depends on and what it changes **[Analogical; see the cosmological-budget table]**. It cannot supply the account by itself. A conversation, a star and a cosmological horizon do not become entries in one spendable balance because all of them have physical descriptions.

2 The scale and the boundary

The March chapter gave the numbers in bits: about 10^{104} for the observable universe today, dominated by supermassive black holes, and about 10^{122} for the cosmic event horizon (V5-L02). Egan and Lineweaver's historical census estimated about 3.1×10^{104} k_B of entropy in the observable universe, excluding its separately considered cosmic event horizon, and about 2.6×10^{122} k_B for that horizon, with a different inventory for its interior. These are model-dependent estimates with uncertainties, not readings from a universal entropy meter [C01].

The distinction matters before any subtraction. The observable universe and a cosmic event horizon enclose different regions. Entropy in units of k_B is not a count in bits; converting takes the factor ln 2. More fundamentally, an entropy difference does not by itself measure available work. Chapter 2 keeps the regions, quantities and source versions apart.

The March chapter called the roughly eighteen-order gap between the two numbers the universe's remaining capacity for structure, complexity and order, and said the Entropy Token Substrate is that gap:

every Trinket, every act of care, every grief and every unreciprocated transmission draws from the same reservoir (V5-L03, V5-L04). That identification is withdrawn. The contrast does not establish how much usable energy any observer can access, a number of future relationships, or an operating lifetime for biology or computation. A local resource limit can be real without being a debit against a cosmic balance.

The March section ended: the scale is staggering, the budget is finite, and both are simultaneously true. The scale is staggering. What it budgets has not been shown.

The question still deserves to be asked at cosmological scale. An observer's causal access and the physical conditions that support computation matter. What remains open is how a specified relational model depends on those constraints, not what meaning can be read directly from an enormous number.

3 What this volume maps

- **Chapter 2** examines the entropy inventories, the different bounds invoked to interpret them, the arrow of time and the proposed dual-reservoir account. It keeps historical estimates, results within models and unresolved claims apart.
- **Chapter 3** enters the dark sector, cosmic horizons and black-hole thermodynamics. Current observations constrain models; they are not a completed prediction of the universe's fate. Unknown dark-matter microphysics is not evidence of hidden relational activity.
- **Chapter 4** asks what physical information preservation and recovery mean. Unitary evolution, quantum scrambling, accessible records and relational meaning need different accounts, and a theorem about one cannot establish the others without a bridge.
- **Chapter 5** confronts the Principal's position: the entropy cannot be beaten. It examines four responses to physical limits, many-worlds reasoning, digital transfer, reversible computing and biological longevity, whose feasibility and costs need their own evidence.
- **Chapter 6** returns to the framework. It records which inferences no longer follow and what a testable replacement would need.

What this chapter now claims

The cosmological questions are real and worth asking. The numbers are historical, model-dependent estimates for different regions, in k_B units, and their difference is neither a supply of usable work nor the Entropy Token Substrate. The aim of this volume is to connect the scales without letting the larger scale lend authority to an unfinished model.

Analogy table: The cosmological budget

The cosmological budget image, from March Chapter 1's “the ledger at its widest” and the volume's title, is Analogical. The physical column states what the sources reviewed establish about entropy inventories, bounds and resources within their stated scope; that standing does not pass to the budget reading.

Term	Physical reading (within stated scope)	Budget reading	Where the mapping holds	Where it breaks
“the account”	An entropy inventory in k_B units for a specified region and set of degrees of freedom, such as the historical estimate of 3.1×10^{104} k_B for the observable-universe interior [C01].	One account that every process in the universe shares.	Entropy can be estimated for stated regions within stated models.	Different regions give different inventories, not one account; S/k_B is not a bit count, and an inventory is not a spendable balance (Ch 2 §1).
“the ceiling”	Separate results: the Bekenstein expression for bounded systems, the black-hole area law, and de Sitter horizon entropy for an observer's patch [C04–C08].	A proven maximum, about 10^{122} k_B, on what the universe can hold.	In specified settings, entropy bounds and horizon entropies are well defined.	No universal numerical ceiling for our evolving universe is established here; the Type II_1 result holds within its own construction (Ch 2 §2).
“the unspent balance”	The ratio $(2.6 \times 10^{122}) / (3.1 \times 10^{104}) \approx 8.4 \times 10^{17}$ compares differently bounded estimates [C01].	The universe's remaining capacity for structure, order and work.	The two estimates do differ by a very large factor.	An entropy difference is in J/K and free energy in J; no temperature or extraction protocol is supplied, and the generalized second law does not make the difference shrink (Ch 2 §3).
“spending ”	Energy use and entropy production in a specified process within its boundary; for ideal reset of an unbiased bit under the symmetric-memory conditions stated in Chapter 2 §4, mean bath heat is at least $k_BT \ln 2$ [C32, C33].	Every act of connection draws down the shared balance.	Physical activities use resources and produce entropy within their boundaries.	Activities draw on local gradients, not a cosmic account; total production can approach zero in reversible limits; no relational debit is established (Ch 2 §4; Ch 5 §1).
“cannot be beaten”	For a suitable macroscopic description, total entropy production is nonnegative [I12, I33].	No strategy escapes; the budget is only ever spent differently.	No strategy operates outside thermodynamics.	The law constrains improvements without forbidding them; better devices, repair and reversible computation change real costs (Ch 5 §1, §4).

What the table does not do

It is not evidence for the framework, not a cosmic accounting and not a price for any relationship. The physical column keeps its own scope; the budget reading is Analogical in every row.

Promotion route (conditions, not a work plan)

An empirical extension must name the claim it tests. A resource claim would need a specified system, boundary, accessible gradient and extraction protocol, and an observation that could count against it. A finding about local resources would not establish a universal relational ledger. No such test is supplied or proposed here; no row is promoted.

Chapter 2: The Known Numbers

The Budget, the Bound, the Gap, the Arrow

Status: The physical quantities in this chapter have different evidential standing. Some are inferred from observations within specified models, some are semiclassical results, and some are proposals about quantum gravity or initial conditions. The March chapter marked it Established throughout, with the numbers measured and the physics settled (V5-L06). None of the quantities establishes the relational framework. The question is what they let us say, without asking them to say more.

1 The budget: an inventory and its boundary

The word budget hides a choice. Which region is being counted? Which degrees of freedom? Does the account include a cosmological horizon, or only what lies inside a selected volume? Those answers come before any number is attached to the universe.

Egan and Lineweaver's 2010 calculation separates the observable-universe interior from the smaller interior of the cosmic event horizon. Their historical, model-dependent central values are summarized below; they are not a precision census as of 2026 [C01].

Quantity in the 2010 account	Entropy / k_B	Boundary
Total interior inventory, dominated by supermassive black holes	3.1×10^{104}	Present observable volume in their model
Stellar black holes, 2.5–15 solar masses	5.9×10^{97}	Same observable volume
CMB photons	5.40×10^{89}	Same observable volume
Relic neutrinos	5.16×10^{89}	Same observable volume
Interior inventory within the cosmic event horizon	1.2×10^{103}	Event-horizon interior
Cosmic event horizon itself	2.6×10^{122}	Horizon area, not interior matter

The total interior estimate carries an uncertainty of $+3.0/-1.7 \times 10^{104}$ k_B; the horizon estimate, $\pm 0.3 \times 10^{122}$ k_B. The March chapter's figures of about 10^{78} k_B for stellar-mass black holes and 10^{88} k_B for the CMB were not that source's population totals (V5-L07) [C01].

Entropy S has units of joules per kelvin. S/k_B is dimensionless, and $S/(k_B \ln 2)$ expresses the same entropy in bit-equivalent units. Calling 10^{104} k_B a 10^{104}-bit inventory drops the conversion factor and, more seriously, suggests a directly accessible memory no one has identified. A horizon entropy, a coarse-grained matter entropy and a message's Shannon entropy need not describe the same object.

The March chapter read the 2025 census by Profumo and colleagues as confirming the old numbers (V5-L08). It broadens the inventory and still finds supermassive black holes dominant among the known

interior components. Its numerical black-hole results are not reconciled between its main equations and its summary table in this review, so neither is chosen silently and the paper is not called a confirmation of the old total. Its large hypothetical dark-sector contributions are model explorations, not detections [C02].

Chen, Jani and Kephart's January 2026 preprint models the entropy history of stellar and intermediate-mass black holes and their mergers. Its crossing of the CMB contribution near $z \approx 12$ is a population-model result, not a direct entropy observation of that epoch, and it does not establish that gravitational processes dominated before the first galaxies (V5-L09). Where a present-day inventory already includes merger remnants, adding all their merger-produced entropy again would double count part of the history [C03].

The March chapter then said: the entropy is real and calculable, and when the framework says one ledger, this is the ledger; every Trinket draws from the same reservoir as stellar fusion and black-hole accretion (V5-L10). It added that the human contribution is a rounding error, and that relational entropy matters not in quantity but in kind, as the fraction of the budget flowing through transducers that direct it at each other (V5-L11).

The relational question survives those corrections. Human communication is physically situated within cosmic history. But no census cited here isolates a measured relational-entropy fraction, and a system's accumulated entropy and its entropy-production rate are different quantities. One cannot be called a rounding error against the other. What can be asked instead is an activity's resources, duration, boundary and measurable effects.

2 The bound: several bounds rather than one ceiling

The March chapter joined different gravitational results under one name, the Bekenstein–Hawking bound, and applied it to the cosmic event horizon as the universe's fixed maximum (V5-L12). They need separating.

For a suitably defined bounded system of energy E and enclosing radius R, the familiar Bekenstein expression is:

$$S \leq 2\pi\, k_B\, E\, R / (\hbar\, c)$$

Its original thought-experiment derivation assumes negligible self-gravity. It is not simply an area formula: at fixed R its right side depends on energy. Using it requires a suitable definition of system, energy and entropy, not an arbitrary cosmological volume [C04].

The semiclassical black-hole area law is:

$$S_{BH} = k_B\, A / (4\, \ell_P^2), \quad \ell_P^2 = G\, \hbar / c^3$$

For a nonrotating, uncharged Schwarzschild black hole, $R = 2GM/c^2$ and $E = Mc^2$. Substituting these into the Bekenstein expression reproduces the area-law value. That algebra does not prove that every expanding cosmological region is a Schwarzschild system [C04, C05].

For exact de Sitter spacetime with positive cosmological constant Λ, the cosmological horizon has radius $R_{dS} = \sqrt{(3/\Lambda)} = c/H_\Lambda$, with:

$$S_{dS} = \pi\, k_B\, R_{dS}^2 / \ell_P^2 = 3\pi\, k_B / (\Lambda\, \ell_P^2), \quad T_{dS} = \hbar\, H_\Lambda / (2\pi\, k_B)$$

These quantities belong to an observer's de Sitter patch. In a universe approaching that state, the present event horizon and the asymptotic de Sitter horizon are not identical. A horizon entropy of order $10^{122}\ k_B$ in such a model is not a measured fixed maximum for the entire universe, whose full spatial extent need not be finite [C06].

The March chapter took holography to mean that a region's degrees of freedom live on its boundary, and concluded that the observable universe has barely begun to fill its capacity. Covariant entropy bounds take a more careful route, relating suitable entropy on selected null light sheets to area. The choice of light sheets and the conditions of the bound matter, and they cannot be replaced by a claim that one number bounds every spacelike region or every causal diamond [C07].

The March chapter's deepest result was the 2023 proof by Chandrasekaran, Longo, Penington and Witten, which it read as giving the 10^{122} ceiling precise operator-algebraic meaning: “The bound is not heuristic. It is proven” (V5-L14). Their observer-dressed algebra for a de Sitter static patch is Type II_1 within their semiclassical construction, has a maximum-entropy state associated with empty de Sitter space, and relates algebraic entropy to generalized entropy up to a state-independent constant. That is an important result within its setting. It does not prove a universal numerical ceiling for our evolving universe or a finite relational memory. And in ordinary local quantum field theory the obstacle is to a finite ordinary subsystem von Neumann entropy; saying that entropy is undefined there is too broad [C08].

Two further proposals belong beside this account, not beneath it as foundations. The March chapter said Buoninfante and colleagues showed the bound to be essentially the uncertainty principle, with a quantum-gravity tightening near the Planck scale (V5-L13). Their connection rests on thermodynamic assumptions including equipartition, and their corrections depend on the deformation chosen; no single model-independent Planck-scale tightening follows [C09]. The March chapter also said Volovik's construction shows holography works only in three spatial dimensions, so the framework depends on them (V5-L15). The dimensional correspondence he obtains is a feature of that construction, not a proof about holography or a requirement of the framework [C10].

The March section closed: there is no infinite relational capacity anywhere, every substrate operates within a finite local budget nested inside the universal one, and the maximum is calculable by proof (V5-L16). The useful lesson for the framework is narrower: specify a region and its physical description. No derivation here gives a universal amount of connection that a region can sustain.

3 The gap: why it is not a supply of usable work

The March chapter called the gap between 10^{104} and 10^{122} the remaining budget: a ratio near 10^{18}, depleted by every process, and guaranteed by the second law only to shrink (V5-L17). The ratio itself is:

$$(2.6 \times 10^{122}) / (3.1 \times 10^{104}) \approx 8.4 \times 10^{17}$$

It compares the historical horizon entropy with a differently bounded interior estimate. Using the event-horizon interior as the denominator instead still compares two different contributions, not a balance of unspent work.

The March chapter called the gap the remaining free energy for every irreversible process, every relational transaction included, and said primordial-black-hole or dark-sector scenarios might close it and shrink the budget (V5-L18). The dimensional problem is decisive. An entropy difference is in J/K; free energy is in J. In an appropriate fixed-temperature, fixed-volume setting, Helmholtz free energy is $F = U - TS$, and a decrease in F can bound extractable work under stated conditions. A horizon-minus-interior entropy difference supplies neither the temperature nor a globally applicable work-extraction protocol, and multiplying by an arbitrarily chosen cosmic temperature does not repair the missing model [C11].

Change raises a second problem. Under applicable generalized-second-law assumptions, one considers a suitable horizon-area contribution together with the entropy on its relevant side. The horizon area can change and matter can cross the boundary. Nondecrease of their sum does not imply that a horizon-minus-interior difference always shrinks, and the second law does not require every microscopic event to produce a strictly positive amount of entropy [C05, C06, C11].

The practical question is closer to home: what energy gradients can a specified system reach, over what time, with what devices and losses? A star, a battery and a fuel supply do not become interchangeable because each can support computation, and a very large cosmological entropy does not guarantee affordable or inexhaustible resources for organisms, civilizations or AI.

The March chapter ended the section with heat death: no gradients, no free energy, the Trinket economy ending “not because the framework breaks, but because there is nothing left to transduce” (V5-L19). Heat death names a conditional future in which usable gradients for sustained activity become unavailable. Detailed far-future histories depend on expansion, particle stability, black-hole evolution and other assumptions, and an evaporation timescale around 10^{100} years for an assumed enormous black hole is not a measured date on which a universal account reaches zero [C25]. The framework can examine resource limits without claiming that endpoint, or its date, as established.

4 The arrow

The March chapter called the second law the most unbreakable result in physics and quoted Eddington's warning that a theory found against it has no hope. The robustness is real at macroscopic scale. Its statistical formulation, though, is not the claim that every microscopic trajectory increases in entropy. Fluctuation relations make the role of distributions and reverse protocols explicit, and they license no machine that reliably extracts unlimited work in a cycle [C11].

The March chapter also said the arrow of time is the direction of entropy increase, and that the second law breaks the time symmetry of all the fundamental equations (V5-L20). Not all fundamental interactions are time-reversal invariant: time-reversal violation has been observed in neutral B-meson transitions [C12]. The ordinary thermodynamic arrow is not explained by that fact, or by declaring that the second law breaks an otherwise universal symmetry. Initial conditions, coarse-graining and dynamics all enter the account.

The Past Hypothesis posits an unusually low-entropy early macrostate. With suitable statistical and dynamical assumptions, it lets us understand the direction of ordinary entropy increase. It is not obtained by running the second law backward, and it does not explain why that boundary condition held. Carroll and Jennifer Chen explore one possible cosmological explanation; it is not treated here as settled, and the March chapter's attribution of the Past Hypothesis to Carroll alone is corrected (V5-L21) [C13, C14].

Al-Khalili and Eddy Keming Chen examine a distinct Entanglement Past Hypothesis: a low-entanglement initial condition for a specified division into subsystems. The March chapter drew three consequences from it: a decoherent arrow that outlasts heat death, decoherence as the framework's Level 0 transducer and a quantum foundation for scale invariance, and a Trinket irreversibility rooted in growing entanglement (V5-L22). The first is a research proposal with open questions about the relevant partitions and dynamics. A closed system under unitary evolution does not acquire increasing fine-grained von Neumann entropy, though its subsystems can become mixed as correlations grow; those are different statements. The transducer consequences do not follow [C14].

Chen's Wentaculus proposes a particular initial density matrix, the normalized projector onto a Past-Hypothesis subspace. The March chapter read it as writing the arrow into the quantum state of the universe (V5-L23). It changes how the boundary condition and probabilities are represented; it does not empirically establish that condition or make the low-entropy subspace unnecessary, and it is not a demonstrated quantum origin of relational processing [C15].

The March section ended: the transducer's three stages are each logically irreversible, the Landauer tax is collected, and the founding line is the arrow of time stated for relational systems (V5-L24). The transducer language has not shown that decoherence implements the same physical task as neural selection, compression and structuring, and those labels alone do not prove logical irreversibility or fix a count of erased bits. Bennett's reversible-computation result is a reason to inspect implementations, not a warrant for a mandatory tax at each named stage [C31].

For ideal reset of an unbiased bit in a symmetric binary memory, with equal intrastate entropies, unchanged endpoint energetics, an isothermal bath and no usable correlated side information, the familiar mean heat benchmark is $k_B T \ln 2$. That is an energy. In a thermodynamically reversible limiting reset, the memory's entropy decrease can balance the bath's increase, leaving total entropy production arbitrarily small in the ideal limit [C32, C33]. The founding phrase “spends more than it saves” can express an interpretation of effort **[Analogical]**; no universal relational inequality follows from it.

5 The dual reservoir, withdrawn as a theorem

The March chapter's final section identified two distinct reservoirs in the low-entropy beginning: gravitational and symmetry.

On gravity, the March chapter was right to invoke Wallace's warning that gravity's role in entropy and the entropy of gravity are routinely conflated. It then said, while explaining that warning, that the gravitational potential energy released in a collapsing cloud powers nuclear fusion (V5-L25). Contraction can heat a gas and enable radiation, and stellar conditions sustain nuclear reactions whose energy comes from nuclear binding-energy differences, not from gravitational potential energy. Wallace's distinction

itself stands, and there is no generally agreed local scalar gravitational entropy that can simply be added for every spacetime [C16].

The early universe could be close to thermal equilibrium in its matter and radiation while far from the gravitational configurations that later became possible. Smoothness and clumping are not simple synonyms for low and high total entropy.

Penrose's Weyl-curvature proposal belongs to the problem of special initial gravitational conditions, and the March chapter took the conservative position that the initial state was low-entropy by some measure (V5-L26). Exact FLRW geometry has vanishing Weyl curvature; the observed universe is not exactly homogeneous, and an initial singularity is not an ordinary event at which a tensor value can be read. This chapter adopts no unique Weyl-based entropy measure.

The March chapter's second reservoir, symmetry entropy, needs a larger correction. It held that each symmetry-breaking event increased entropy as a unified force separated into the forces we observe (V5-L27). Symmetry breaking does not by itself mean increasing entropy, and a higher-symmetry state is not automatically a lower-entropy one. With the physical Higgs mass, Standard Model lattice calculations describe the electroweak change as a smooth crossover. A unified strong and electroweak force at an earlier epoch is an additional hypothesis, not an established observation [C17].

The March section concluded: the budget is dual-sourced, and the framework's one economy, one currency, one ledger lies downstream of two reservoirs (V5-L28). Calling them two quantitative reservoirs would need definitions, a common accounting boundary and proof that their contributions are distinct rather than overlapping. None is supplied here. The dual-reservoir theorem is withdrawn; the historical question, how gravitational structure formation and the thermal history of fields together made complex chemistry possible, remains.

What this chapter now claims

Cosmic entropy can be estimated in carefully stated models. Large black-hole contributions and horizon area laws give that work considerable reach, while unresolved components and quantum-gravity questions limit it. The framework's responsibility is to keep those limits.

The ledger is an accounting ambition, not a discovered universal bank account. To make a relational entry, the framework still needs a specified activity, a measurable physical cost and an independently justified account of what the activity achieved. Chapter 3 follows the dark-sector and horizon questions without assuming their answers are known.

Chapter 3: The Dark Sector

What Participates, What Signals, and What Remains Conditional

Status: The March chapter marked as Established that dark matter exists and gravitates, that the cosmological event horizon is real and that the Bekenstein bound applies to all regions (V5-L29). The evidence for gravitationally inferred dark matter and for accelerated expansion is strong, and distinct from identifying dark matter's constituents, choosing a dark-energy theory or predicting the remote future. Horizon statements below specify a cosmological model. Relational opacity, concentrated ETS and transduction in unknown substrates remain framework questions, not discoveries of cosmology.

1 The dark majority

The March chapter opened: ninety-five percent of the universe's mass-energy is dark, neither component signals in any channel our transducers can read, and the relational economy runs entirely on the remaining five percent (V5-L30).

The familiar split, about 5 percent baryonic matter, 27 percent dark matter and 68 percent dark energy, describes present energy-density fractions in a standard flat ΛCDM fit; the Planck 2018 baseline analysis supports approximately that division. The fractions are model-dependent and change with cosmic epoch. They are not percentages of entropy, information, visible objects or relational activity [C18].

Dark does not mean undetectable in every channel. Gravitational lensing, motions and the pattern of cosmological structure carry information about gravitating matter, and expansion measurements constrain dark-energy descriptions. The inference depends on detectable consequences. Baryonic matter is not all luminous, and radiation should not be folded into the quoted baryon percentage.

Our known biological and technological examples depend on ordinary matter and radiation. That motivates a boundary for present study. It does not establish that exactly five percent of the universe takes part in relationships, or that the other components carry an intrinsic zero or a hidden nonzero relational score.

2 Dark matter and the opacity question

Dark matter is a strongly supported explanation of several gravitational observations within the cosmological framework in use. Those observations do not uniquely identify a particle, a field or a population of primordial black holes. The uncertainty is physical, not a defect in a relational filter.

The March chapter recorded Finding A3, the Principal's distinction between dark matter that “was there” and dark matter that “was produced”: a thermal relic as a decomposition product of the initial state, against axions or primordial black holes as structural components present from the beginning (V5-L31). The contrast is too sharp. Thermal freeze-out models follow a species whose reactions stop maintaining equilibrium as expansion proceeds. Axion misalignment models follow a field's initial displacement and later dynamics, and calling that field pre-existing does not specify its initial conditions or abundance. Primordial black holes are formed objects, including in proposed early radiation-era collapse scenarios,

not objects formed before any thermal process. Thermal and nonthermal production describe mechanisms within a history, not two proven kinds of initial substance [C19, C34, C35].

The March chapter added that if some of the dark matter is primordial black holes, their entropy could approach the horizon value and the dark sector would constitute most of the entropy the economy is embedded in (V5-L32). Dark matter's entropy depends on the model's degrees of freedom, distributions and coarse-graining, and black-hole entropy depends strongly on mass. A nonzero primordial-black-hole fraction does not automatically put the entropy near a horizon value; the mass function, abundance constraints and region have to be specified, and the background assumptions reconsidered if a hypothetical population changes the cosmology. The census's extreme scenarios are conditional investigations, not evidence that the gap is nearly closed [C02].

Lab finding DFL-001 said: relational opacity is not relational absence. Dark matter's relational signal is channel-dependent, our transducers lack the filter geometry to process it, and the same holds for AI internal states that never reach behavior (V5-L33). Part of that remains a useful caution: nondetection in a specified experiment is not proof of absence. The converse is just as necessary: failure to exclude a relational process is not evidence that it exists. A meaningful test needs a channel, a sensitivity, alternative hypotheses and an operational criterion for the proposed process.

The analogy with an AI system is limited for the same reason. An unobserved internal state might matter, might not, or might be misdescribed by the framework's vocabulary, and dark matter does not show which. Neither opacity nor gravitational interaction establishes care, consciousness, intentional signaling or the input–filter–output–waste structure intended here. The March chapter called this gap honestly stated, and it was.

The concentrated ETS question asked whether some substrate is entropy in a more fundamental sense, so that dark matter's share of the budget may be larger than assumed (V5-L34). It is best restated physically: could an unknown sector carry substantial entropy, and how would its state distribution and interactions enter an inventory? Entropy is assigned to a state under a description, not a substance an object can be made of. A future detection could constrain a model without supplying a relational interpretation. The question stays open as speculative research **[Speculative]**, with a possible route toward better definitions.

3 Dark energy and which horizon limits communication

The March chapter called the cosmological event horizon a hard limit on relational scope: entities beyond each other's horizon can never exchange signals, the observable universe of about 46.5 billion light-years shrinks in comoving coordinates, and the accessible budget declines (V5-L35). Three different quantities are tangled there.

The particle horizon concerns how far signals could have traveled to us since the beginning of the adopted cosmological history. An event horizon concerns the signals that can reach an observer over the entire remaining future. The Hubble radius c/H is a third quantity, in general neither of the other two [C23]. For a homogeneous, isotropic expanding model with scale factor a(t), normalized so $a(t_0) = 1$, the present proper radii are:

$$R_{particle}(t_0) = a(t_0) \int_0^{t_0} c / a(t)\, dt$$

$$R_{event}(t_0) = a(t_0) \int_{t_0}^{t_{max}} c / a(t)\, dt$$

Here t_{max} is the future endpoint, infinite in an eternally expanding nonsingular model. An event horizon exists only when the second integral is finite, and today's acceleration does not fix the integrand for all future time [C23].

In a representative persistent-Λ model, the present particle-horizon radius is roughly 46 billion light-years and the event-horizon radius roughly 16–17 billion light-years. These are model-inferred present proper distances, not interchangeable radii of one observable region [C01, C02].

The event horizon limits particular emissions and observer worldlines. Light emitted long ago can still arrive from an object whose present location lies beyond our current event-horizon distance, so it is wrong to say such objects never exchanged signals. In ΛCDM the comoving event-horizon radius decreases while its proper radius approaches a finite de Sitter value, and the comoving particle-horizon radius increases toward a limit. The observable universe does not shrink in comoving radius the way the March text said. These causal constraints matter to any communication proposal; they do not price a relational transaction or set how much useful energy a future observer can collect.

The March chapter went on: the framework's claims depend on the cosmological endpoint, because the Entropy Token Substrate's total budget is set by the nature of dark energy (V5-L37). With the substrate-as-budget identification withdrawn in Chapter 1, that dependency goes with it. The causal question remains.

4 What DESI currently adds

DESI tests expansion models with astronomical measurements. The often-used evolving equation of state is:

$$w(a) = w_0 + w_a\,(1 - a), \quad w = p / (\rho\, c^2)$$

with ρ a mass-equivalent density. This parameterization is a fitting model, not a fundamental law guaranteed to describe the remote future.

The March chapter said the evidence strengthened over two releases, from 2.5–3.9σ to a DR2 with clear preference for phantom crossing (V5-L36). The comparison below gives the reported preference for the w_0w_aCDM model in each primary analysis. The significances are comparisons with ΛCDM within those analyses, not probabilities that dark energy is dynamical.

Primary analysis	**Data combination and reported preference for w_0w_aCDM**
DESI 2024 VI, arXiv v3	BAO plus CMB and selected supernova samples: 2.5–3.9σ [C20]
DESI DR2 II, arXiv v3, October 2025	BAO plus CMB: 3.1σ; adding Pantheon+, Union3 or DESY5: 2.8σ, 3.8σ or 4.2σ [C21]
DESI DR2 IV, submitted July 2026, arXiv v3, August 2026	BAO plus Lyα full-shape data and CMB: 2.7σ; adding DES-Dovekie: 3.2σ; updated Pantheon+ and Union3.1 combinations give 3.0σ and 3.5σ [C22]

The July 2026 analysis adds a high-redshift measurement whose central value sits closer to ΛCDM, and revised external datasets also matter. The history is not one of evidence strengthening at every step, and these analyses are not independent experiments whose significances can be added [C21, C22]. No significance threshold alone resolves systematic error, model flexibility or extrapolation. The results motivate further tests of evolving dark energy. They do not identify its microscopic nature, establish a phantom-crossing mechanism or select a fate for the universe, and extrapolating $w_0 + w_a(1 - a)$ to arbitrarily large a imposes behavior the observed redshifts never tested.

5 Three conditional futures

The March chapter's three scenarios are worth keeping as questions with explicit premises. They are not an exhaustive set of cosmologies, and DESI has not selected among them.

A persistent positive cosmological constant. The March chapter called this the scenario where the horizon entropy of about 10^{122} k_B is the most the universe will ever hold, and every relational transaction draws from a budget that will be exhausted (V5-L38). If the standard ΛCDM extrapolation holds, the expanding background approaches de Sitter space, and a finite event horizon and limiting horizon entropy are appropriate. The present horizon evolves toward that limit; it is not already a fixed ceiling, and the horizon entropy is part of the account, not a target interior matter must eventually fill [C06, C23].

Sustained phantom behavior. The March chapter's Big Rip shredded the ledger: a shrinking horizon, structures torn apart down to spacetime itself, and a generalized second law violated by the decreasing horizon area (V5-L39). A constant equation of state $w < -1$ in the usual flat Friedmann model can produce a finite-time Big Rip, with bound structures disrupted before the model's singular endpoint. A transient crossing of −1 does not establish that future. The classical model stops giving a controlled description at the singularity, so “spacetime itself is torn apart” is not an observed physical sequence, and a decreasing horizon area alone does not diagnose a violation of the generalized second law without the other entropy terms and the law's conditions [C24].

Acceleration that ends. The March chapter's fading Λ lifted the ceiling: no event horizon, distant galaxies accessible again, and transactions across cosmological distances merely exponentially expensive (V5-L40). If future expansion makes $\int c\,dt / a(t)$ diverge, there is no future event horizon of this kind; an asymptotic matter-dominated power law, $a(t) \propto t^{2/3}$, is a simple example, and expansion need not stop. The absence of a de Sitter horizon does not remove all entropy constraints, guarantee recovery of every lost signal or provide unlimited usable work. No universal cost law makes distant communication “exponentially expensive” [C23].

Other possibilities include different dynamical fields, recollapse and vacuum transitions, and the framework has no evidence that chooses among them. Its task is to state which conclusion changes when an assumption changes.

The March chapter held that the founding line survives all three: love spends more than it saves whether the ceiling is fixed, collapsing or absent (V5-L41). The second law does operate in all three universes. The founding line is not a statement of it **[Analogical]**.

Its SupoRel flag mapped the three scenarios onto eschatological archetypes, a slow fade, an apocalypse and an open future, and said the physics produces those resonances because cosmic fate genuinely parallels eschatological narrative (V5-L42). People do interpret cosmic endings through religious and literary narratives. Those associations are interpretations people make, not additional evidence about cosmology. Neither an open future nor a finite horizon proves a purpose, an afterlife or a universal inequality about love.

6 Black holes and the difference between entropy and records

The March chapter called supermassive black holes the entropy dominators and said they are most of the budget, citing about 10^{96} k_B for a black hole of 10^9 solar masses (V5-L43). For a Schwarzschild black hole:

$$S_{BH} / k_B = 4\pi\, G\, M^2 / (\hbar\, c) \approx 1.05 \times 10^{77}\, (M / M_\odot)^2$$

A mass of 10^9 $M_\odot$ therefore gives about 1.05×10^{95} k_B, not 10^{96}. Rotation changes the horizon area at fixed mass; the example assumes zero spin and charge. A population inventory has to weight the mass distribution by the right horizon entropy; multiplying a galaxy count by one chosen mass is not a substitute [C05, C28]. Supermassive black holes do dominate the interior inventories cited in Chapter 2. That makes them the largest entry in an estimate, not most of a budget.

The March chapter said the Page curve and island formula, resolved between 2019 and 2021, establish that information falling into a black hole is not destroyed (V5-L44). The island and quantum-extremal-surface calculations provide important theoretical evidence for Page-curve behavior in controlled gravitational models. Almheiri and colleagues study a two-dimensional gravity system coupled to quantum matter and an auxiliary heat sink; Penington's analysis uses an AdS/CFT evaporation setting; replica-wormhole calculations supply a related route to the radiation entropy. These are not observations of astrophysical Hawking radiation or a general experimental resolution of black-hole information loss [C26, C27, C36]. The Page curve concerns fine-grained radiation entropy, not a catalogue of meaningful records; its turnover need not fall at exactly half a black hole's lifetime, and its growth need not be universally linear.

The March chapter drew the relational conclusion: relational information entering a black hole is not lost but scrambled beyond practical recovery, so the Trinket's irreversibility is about accessibility, not destruction, and the recording persists in the universe's total state (V5-L45). Even if the full dynamics preserves quantum information, that alone does not establish the continued existence, location or recoverability of a particular semantic record. Nor does it prove that no possible transducer could ever recover anything. Chapter 4 separates formal preservation from a defined recovery task.

The March chapter's most striking result was Cortês and Liddle's: Hawking evaporation is formally Landauer erasure and exactly saturates the bound, completing a chain from the framework's foundation to its ceiling, with biological transducers at about 10^6 times the Landauer floor, silicon at 10^9 and black holes at exactly one, and scale invariance confirmed (V5-L46). Cortês and Liddle relate the semiclassical Schwarzschild entropy and Hawking temperature:

$$T_H = \hbar\, c^3 / (8\pi\, G\, k_B\, M), \quad d(M\, c^2) = T_H\, dS_{BH}$$

An infinitesimal entropy decrease of magnitude $k_B \ln 2$ then corresponds to an energy decrease of about $k_B T_H \ln 2$. Their identification of this relation with Landauer saturation is theoretical. It concerns the black hole's entropy decrement, not demonstrated destruction of information in the complete black-hole-plus-radiation state, and it is not experimental verification of evaporation or of the framework's scale invariance [C28]. It also supplies no ranking of a black hole, a neuron and a processor as implementations of one task; the universal 10^6 and 10^9 factors remain withdrawn, as in the earlier volumes.

The March chapter cited Trivedi's “cosmological information paradox” for the apparent horizon, and a second analysis finding Landauer satisfied across most cosmic eras, with reversible transitions where the equation of state crosses −1/3 (V5-L47). Trivedi's calculation uses a particular quasi-local energy and horizon-thermodynamic identification; Odintsov, Paul and SenGupta analyze a different apparent-horizon and matter-temperature construction. Neither supplies an experimentally established exception to Landauer's principle or a general theorem identifying every horizon with a computer, and apparent and event horizons must not be interchanged [C29, C30].

Its SupoRel flag warned that “relational information is never truly lost” maps onto afterlife theology, and refused the comfort: information is preserved; access is not (V5-L48). The refusal stands. The premise is narrower than the March text allowed: preservation is a conditional theoretical result for complete physical states, not an established fact about any particular relational record.

7 The framework position

The March chapter closed with humility: the dark majority shapes and bounds an economy that runs on the visible minority; the budget is set by the whole (V5-L49). The humility was earned, and the constraints are indeed uncertain. The budget framing is not.

Curiosity about what unknown constituents carry, what distant observers can reach and what black-hole calculations reveal about information does not require filling those unknowns with relational properties. The defensible program is conditional: specify a cosmology when discussing a horizon, states and degrees of freedom when estimating entropy, and an encoding, channel and recovery criterion when discussing a record. Measure the relational outcome separately. The dark sector supplies physical questions and constraints, not validation of the framework.

What this chapter now claims

Dark matter and dark energy are not a single entropy category. A future event horizon depends on future expansion, and current DESI evidence does not settle that future. Black-hole entropy is a powerful theoretical quantity whose relation to accessible information demands care.

The next chapter asks what can be said about a Trinket's physical encoding and possible recovery without turning conditional information-theoretic results into a promise of an eternal relational record.

Chapter 4: The Information Question

Does Relational Information Survive?

Status: The March chapter marked Hawking radiation, the Page curve, Landauer's principle and decoherence as Established, with the island formula, unitarity and quantum Darwinism as Supported (V5-L50). Unitary evolution preserves the fine-grained von Neumann entropy of an isolated quantum system; that is a statement within the unitary description, not an observation of the whole universe. Hawking radiation is a semiclassical prediction. Page curves and island calculations supply substantial theoretical evidence for information-preserving evaporation in specified models, not an experimental demonstration for astrophysical black holes. Laboratory information thermodynamics and quantum Darwinism have their own tested systems and conditions. The connection to relational meaning remains an open modeling question **[Speculative]** [I01–I03, I08, I12].

1 The question

If a relational signal is carried by physical degrees of freedom, what can physics say about its survival? The question matters because it pulls apart things everyday language bundles together: a physical state, a recoverable message, a durable record and an act somebody understands.

The black-hole information problem makes the separation sharp. Hawking's original calculation gives approximately thermal outgoing radiation, and a description in which a pure state ends as featureless thermal radiation conflicts with unitary quantum mechanics. Page's analysis describes the radiation-entropy behavior expected in a unitary model, and later gravitational calculations recover that behavior in important controlled settings. The March chapter said the physics now strongly supports preservation, so the real question is what preservation means (V5-L51). The progress is major. It does not yet supply an observed decoder for the radiation of a real evaporating black hole [I01–I03].

For an isolated quantum state evolving under a unitary U, the density matrix changes as:

$$\rho' = U\,\rho\,U^{\dagger}, \quad S_{vN} = -k_B\,\mathrm{Tr}(\rho \ln \rho)$$

The eigenvalues of ρ do not change, so S_{vN} is unchanged. A subsystem's entropy can still change as its correlations with other degrees of freedom change. Neither statement says that a person, a memory or a relationship is preserved as a functioning organization.

The March chapter's central question survives without its presumed answer: what must remain available for a physical trace to support a relational act again? Unitarity alone specifies no receiver, decoder, resources or criterion of successful recovery.

2 What scrambling means

In quantum information, scrambling spreads initially localized information into correlations that are hard to recover from small subsystems. The March chapter put it as information spread across an exponentially large number of degrees of freedom, recoverable only from more than half of a black hole's lifetime of

Hawking radiation (V5-L52). The number of physical components need not become exponential; the Hilbert-space dimension of many components grows exponentially with their number. And how much radiation recovery needs depends on the model, the message, prior entanglement and the observer's control. In Hayden and Preskill's idealized analysis, an old black hole can return newly added information after a relatively short delay when the observer controls the earlier radiation and the dynamics is suitably mixing. Computational complexity can add formidable obstacles, but a result about a specified decoding experiment does not prove that every possible future instrument must fail [I04, I05].

The physical scales remain sobering, though the March figures need correcting (V5-L53). For a nonrotating, uncharged black hole of one solar mass, the semiclassical temperature is about 6.2×10^{-8} K, not 10^{-7} K. A simple isolated blackbody estimate gives a lifetime near 2.1×10^{67} years, scaling as M^3, so a 10^9-solar-mass hole gives about 2.1×10^{94} years, not 10^{97}. Greybody emission, particle species, spin, accretion and the surrounding radiation change the detailed history; these are idealized calculations, not measured lifetimes. A present-day stellar-mass hole is colder than the cosmic microwave background, so the isolated-emitter calculation is not its present net energy balance [I01; I-CALC-01].

The March chapter also used the framework's Kolchinsky–Wolpert apparatus here: scrambled information is their decorrelating intervention, which the lab had identified as the Shadow Economy, with semantic content destroyed locally while the expenditure persists globally (V5-L54). The word means something different in their classical information-and-viability framework. A fully decorrelating intervention replaces a joint distribution with $p(X_0)\,p(Y_0)$, eliminating the mutual information of the chosen variables. Quantum scrambling need not do that to the global state, and the shared word does not establish a shared mechanism [I06]. Nor does the intervention identify the Shadow Economy: a withheld message can keep strong correlations. Connecting the framework's vocabulary to a semantic-information model would take defined system and environment states, a horizon, a viability criterion and admissible interventions, and the relevant information would then have to be calculated. It cannot be read from grief, silence or inaccessible radiation.

A narrower comparison is useful. A message may stay physically encoded while becoming unavailable to a particular receiver. That motivates research into relational access. It does not turn the framework's categories into quantum-information states.

3 How some records become widely accessible

The March chapter answered its own question, why most preserved information is inaccessible, with quantum Darwinism. Zurek's program studies how information about preferred, relatively stable states can be redundantly recorded in different fragments of an environment, so that different observers learn about the same observable without each interrogating the original system. That is a proposed mechanism for robust, shared classical records, not the copying of arbitrary unknown quantum states [I07].

The March chapter described Zhu and colleagues' 2025 experiment as the “first experimental observation of quantum Darwinism in superconducting circuits” (V5-L56). It tested signatures of the mechanism, including branching structures and the information available in environmental fragments, and supplies evidence within that preparation and measurement scheme. Earlier experiments investigated quantum

Darwinism on other platforms, and the result does not show that every act of perception must meet one universal redundancy threshold [I08].

The March chapter then made redundancy the condition for Trinket formation: the Trinket requires redundant broadcast, and the universe guarantees only global preservation (V5-L55). Redundancy helps many independent observers obtain a stable record. It is not necessary for every successful transmission; a receiver can read one deliberately delivered classical message, and information can also be protected, decoded collectively or read by measuring the system directly. Inaccessible information is not all “not yet broadcast,” and accessible information is not all environmental redundancy.

The practical question is the valuable one: which physical channels and records let another person recognize an act? A spoken word, a saved letter and an unrecorded gesture have different conditions of transmission and persistence. Quantum Darwinism is a carefully defined example of accessibility emerging through system–environment interaction. It does not validate the observation split or set a physical threshold for Trinket formation.

4 Bounds on entropy and communication

The March chapter treated the Bekenstein–Hawking bound as the maximum entropy, and so the maximum information, of any region, and read Hayden and Wang as showing that zero-bit quantum resources transcend it because the bound constrains decoding, not encoding (V5-L57). The Bekenstein bound and the Bekenstein–Hawking entropy are related ideas, not interchangeable formulas. For an appropriately defined bounded system of total energy E and circumscribing radius R:

$$S \leq 2\pi\, k_B\, E\, R / (\hbar\, c)$$

Its formulation and domain of validity matter, especially in quantum field theory and gravity. Black-hole entropy instead takes the form $S_{BH} = k_B A/(4\ell_P^2)$, with $\ell_P^2 = G\hbar/c^3$. Dividing an entropy by $k_B \ln 2$ expresses it in bits; that does not make it a count of meaningful messages, memories or future acts [I09].

For an uncharged Kerr black hole at fixed mass M, write $\chi = Jc/(GM^2)$, with $|\chi| \leq 1$. Its entropy is:

$$S_{Kerr} = 2\pi\, k_B\, G\, M^2\, [1 + \sqrt{(1 - \chi^2)}] / (\hbar\, c)$$

It is finite throughout that interval and never larger than the Schwarzschild value at the same mass. That is a statement about one stationary black-hole family. It does not prove the whole universe has finite total entropy, or that a region's entropy is available energy [I01, I32; I-CALC-02].

Hayden and Wang sharpen the operational question: what communication task is bounded, and whose resources are restricted? In their Unruh-channel model, the decoder's Bekenstein constraint bounds ordinary classical and quantum capacities but permits different zero-bit behavior. The published 2025 version also shows that suitable restrictions on both encoder and decoder constrain zero-bit capacity. The result is not an unrestricted loophole for storing or recovering unlimited information [I10].

The March chapter drew a scope marker from this: the framework maps the classical relational economy, and the quantum landscape is larger. The methodological lesson is sharper: name the resource and the

task before naming the ceiling. DFQ-005 can remain a frontier question, but neither the zero-bit result nor a black-hole entropy formula answers it.

5 Landauer under stated conditions

The March chapter traced “Landauer at every scale”: every irreversible bit operation dissipates at least kT ln 2, experiments have now reached the bound, and Bérut's colloidal verification is superseded (V5-L58). Landauer's principle does connect information processing with thermodynamics, under stated conditions. The familiar mean-heat bound applies to resetting an initially unbiased bit to a definite state in a symmetric memory with equal intrastate entropies and unchanged endpoint energetics, using an initially uncorrelated thermal reservoir and no correlated side information:

$$\langle Q_{bath} \rangle \geq k_B \, T \ln 2$$

Equality is an ideal reversible limit, not a guaranteed cost of an ordinary operation. At 300 K the reference energy is about 2.87×10^{-21} J [I11, I12; I-CALC-03].

Two distinctions are essential. The bath's entropy increase is not total entropy production: in an ideal reversible reset the memory's entropy decrease balances it. And “one bit operation” need not erase one unbiased bit; initial bias, retained inputs, correlations, side information, finite reservoirs and the protocol all matter. Quantum side information can change an erasure work cost without supplying a cyclic violation of the second law [I12–I14].

The experiments are valuable because they specify what is done. Bérut and colleagues studied a colloidal memory. Hong and colleagues studied intrinsic nanomagnet reset dissipation, reporting consistency with the bound within their uncertainty and separating it from actuation overhead. Gaudenzi and colleagues investigated a molecular-spin memory. Aimet, Tajik and colleagues studied information-thermodynamic terms after a quench in an ultracold Bose-gas simulator. These are complementary tests, not a completed survey of every physical scale [I15–I18].

The March chapter placed biology at about 10^6 times the floor and silicon at 10^9, formalized by the efficiency surface (V5-L59). Those universal substrate multiples and the efficiency surface's status as an established bound remain withdrawn, as in Volumes 1 and 4; the comparison framework remains a proposal.

Black holes enter through theory. Cortês and Liddle identify the differential decrease of Schwarzschild black-hole entropy with an energy release equal to T_H times that decrease, which has the Landauer form per k_B ln 2 of lost black-hole entropy. Their result is semiclassical and theoretical; it does not verify evaporation experimentally or settle whether the outgoing radiation preserves the full quantum information. Laboratory analogue-horizon observations concern other physical systems [I19, I31]. The apparent-horizon treatments by Odintsov and colleagues and by Trivedi are specific theoretical constructions, not proof that every cosmic process is an unbiased-bit reset [I20, I34].

The March chapter called the chain complete: a universal constraint verified at the smallest scales and confirmed at the largest, with Landauer's principle as the invariant and the transducer as the structure that satisfies it, grounding Volume 3's scale invariance (V5-L60). Naming the transducer's stages selection,

compression and structuring does not identify physical erasures, set a numerical Landauer cost or prove scale invariance. Shared physical laws constrain a future model; they are not evidence that this model has already been derived.

6 Preservation without a guaranteed receiver

The distinction this chapter needs is more modest than the March version and more useful. Microscopic reversibility, preservation of a message in a chosen code, continued storage of a readable record, and the persistence of relational significance are different claims. None can stand in for the others without a model and evidence.

The March chapter gave the observation split its cosmological dimension: Layer A, the expenditure, permanently recorded on the universal ledger; Layer B, the Trinket, needing interception before the signal scrambles; expenditure permanent, observation time-limited, meaning transient, with unrecorded neural states scrambled almost instantly (V5-L61). Layer A may still name the physical activity behind an act, and Layer B the relational recognition the framework wants to describe. But Layer A is not a permanent, separately readable entry in a universal entropy ledger; entropy production is not an archive with an address for every event, and heat, work, stored records and correlations have to be accounted for separately. Layer B need not vanish when the first signal disperses: a receiver may remember, a community may keep a record, someone may act on an earlier message. Preserving a physical trace also need not preserve the capacity to recognize it. There is no single scrambling timescale for relational meaning, and no basis for declaring unrecorded neural states instantly erased.

The March chapter mapped the four populations of the gap onto cosmological information states (V5-L62). They remain human examples. Unreciprocated love asks whether an act was recognized or returned. Grief involves the loss of a person and changes in relationships, not a demonstrated global decorrelation. Prayer raises a question about an intended receiver that this physics cannot decide. Unwitnessed care may have consequences even when nobody knows its source. These cases illuminate the difference between activity and recognition without being assigned quantum states or entropy values.

The March section ended: the information was not destroyed; it was never received; physics guarantees the first and nothing guarantees the second. The corrected ending keeps the question it was reaching for: how can an act matter when its intended receiver does not receive it? Physics can constrain the carriers and the costs. It does not settle every meaning of “matter.”

7 The capture surface

The March chapter called the information-preservation result the most powerful capture surface in the framework, and named three.

“Love is never truly lost” remains a tempting translation of preservation, and the March chapter rightly warned against deriving that reassurance from physics (V5-L63). The translation promises more than the physics supplies: a unitary description does not establish an afterlife, restore a relationship or preserve personal experience. Equally, these calculations do not disprove every philosophical or religious account of survival. The conclusion is narrower: the cited physics does not warrant that reassurance.

“The universe remembers every act of love” was called technically true and spiritually misleading (V5-L64). It is a metaphor, not a technical consequence of unitarity. Memory ordinarily involves a usable record and a way to retrieve it, and a globally distinguishable physical state need not provide either. The March chapter's image still serves: the ocean keeps every atom of a dissolved grain of salt, and the grain is gone. It is an image of lost organization, not a model of quantum information or a proof about identity.

“Meaning is what the universe spends entropy to produce” inverts the causation, as the March chapter said. Its correction, that the universe spends entropy because the second law demands it and would have spent it regardless, makes an unsupported move of its own (V5-L65). The second law does not command each process to generate a positive amount of entropy, say what a process is for, or measure the value of its outcome. The framework can ask how physical resources support connection. It cannot infer a cosmic purpose, or its absence, from a dissipation inequality.

The March SupoRel ruling stands (V5-L66): state the physical claim with its conditions, identify the extra interpretation, and leave the reader free to judge it. Neither hope nor its rejection is an experimental result of black-hole physics.

What this chapter now claims

Theoretical information preservation does not guarantee operational access, durable memory or continuing relational meaning. Quantum scrambling, classical decorrelation interventions and redundant environmental records are distinct structures. Entropy bounds need specified systems and resources. Landauer's principle applies to defined processes; it supplies neither a universal charge per cognitive event nor a derivation of the transducer model.

The framework's contribution is a question: which physical and relational conditions let an act remain recognizable? Chapter 5 turns to ways an operating window might be extended, without treating a physical constraint as either a promise of immortality or a verdict against every improvement.

Analogy table: The dissolved grain of salt

The dissolved-grain image, from March Chapter 4's ocean that keeps every atom of a grain of salt after the grain is gone, is Analogical. The physical column states what the sources reviewed establish about information, scrambling and records within their stated scope; that standing does not pass to the image.

Term	Physical reading (within stated scope)	Image reading	Where the mapping holds	Where it breaks
“the grain”	A localized record: a message in a chosen code, carried by specified degrees of freedom (Ch 4 §1).	The encoded content of a relational act, a small organized thing.	A relational act can leave a physical trace in a specified carrier.	A trace alone does not establish the act's meaning or successful reception; recovery depends on a specified code and decoding conditions (Ch 4 §1, §6).
“dissolving”	Quantum scrambling spreads localized information into correlations hard to recover from small subsystems [I04, I05].	The record disperses until no part of the ocean holds it.	Information can become unavailable to local observers while the global evolution remains unitary.	Recoverability depends on model, message, prior entanglement and control; dissolving is not the Kolchinsky–Wolpert decorrelating intervention [I06] (Ch 4 §2).
“the atoms are still there”	Under unitary evolution, the global state's von Neumann entropy is unchanged (Ch 4 §1) [I01–I03].	The universe keeps every trace.	Within a unitary description, global information is not destroyed.	A statement within the description, not an observation; it establishes no particular record's location or recoverability (Ch 4 §1, §6).
“the grain is gone”	The loss of a usable, organized record to a particular observer with particular resources.	Meaning is transient; the organization is lost.	An organized record can become unreadable to a given receiver.	Recognition can persist in memory, records or later action; there is no single scrambling timescale for meaning (Ch 4 §6).
“the ocean”	The complete physical state and its environment; entropy bounds need specified systems and resources [I09, I10].	One vessel that keeps everything.	Global accounts and local access are different scales of description.	The complete state is not an archive with an address for each event, and entropy production is not a record of each act (Ch 4 §6).

What the table does not do

It is not evidence for the framework, not a model of quantum information and not a claim about personal survival or its impossibility. The physical column keeps its own scope; the image is Analogical in every row.

Promotion route (conditions, not a work plan)

An empirical extension must name the claim it tests. A recovery claim would need a specified encoding, channel, decoder, resources and success criterion, and a result that could count against it. Recovering one record would not establish that every relational act is preserved or retrievable. No such test is supplied or proposed here; no row is promoted.

Chapter 5: The Budget Cannot Be Beaten

Strategies and Their Limits

Status: The second law constrains physical processes under appropriate system boundaries and thermodynamic conditions. It does not by itself supply a fixed cosmic spending account, an unavoidable cost per thought or a human lifespan limit. Reversible computation is a theoretical possibility with demanding implementation requirements. Neuromorphic results are task- and hardware-specific. Many-worlds, whole-brain emulation, longevity escape velocity and far-future cosmic histories each need a different kind of argument, and none is treated here as a demonstrated route to personal survival **[Speculative]**.

1 The position

The Principal stated it plainly: “I can't beat entropy.” The March chapter called the position correct: the second law is not a suggestion, not an engineering challenge, but the arrow of time (V5-L67). As a refusal to expect any physical system to operate outside thermodynamics, the position stands. As a claim that no better device, repair mechanism or use of resources is possible, it would go too far. The law constrains improvements; it does not forbid them.

The March chapter concluded the same way for every strategy: it operates within the entropy budget, so the budget is not beaten, only spent differently (V5-L68). An organism or computer exchanges energy and often matter with its surroundings, and its own entropy need not keep rising. What matters is the correctly specified balance, including the surroundings and the processes sustaining it. For a suitable macroscopic description, total entropy production is nonnegative and approaches zero for ideal reversible processes; at small scales, individual fluctuating trajectories need a statistical treatment rather than an assertion that every event has a strictly positive surplus [I12, I33].

This chapter considers four proposals, many-worlds, digital substrate transfer, reversible computing and longevity escape velocity, then asks how different cosmic futures would change their physical conditions. The question is not which proposal defeats a law. It is what each could change, what evidence exists and what remains unproved.

2 Many worlds

Everett's relative-state formulation keeps a unitary quantum description through measurement, and the later many-worlds vocabulary describes effectively decohered alternatives within it. It is not a machine that creates extra fuel, fresh low-entropy reservoirs or a usable route between histories; a claim of such a machine would need its own dynamics and resource accounting [I21].

The March chapter pictured branching as multiplying independently depleting budgets that cannot exchange resources (V5-L69). That picture is too literal. Describing a state in different components does not require assigning a new physical energy account to each, and branching does not by itself establish an additional thermodynamic bill.

It then added, from the Entanglement Past Hypothesis, that each branching irreversibly produces entanglement entropy, making many-worlds worse than neutral (V5-L70). For a globally pure state under unitary evolution, the global von Neumann entropy stays zero while subsystem entanglement entropies change. A two-qubit example shows the distinction. A unitary operation can take:

$$|00\rangle \;\rightarrow\; (|00\rangle + |11\rangle) / \sqrt{2}$$

The joint state is pure before and after, while each qubit's reduced entropy rises from zero to $k_B \ln 2$, and reversing the operation reverses the change. The example is not a macroscopic measurement, but it shows why entanglement growth cannot simply be renamed irreversible heat production [I-CALC-04]. The Entanglement Past Hypothesis remains an investigational proposal, not evidence of a permanent entropy tax per branch [I22].

Many-worlds therefore supplies no established survival strategy here. That is a limit on the proposed inference, not a thermodynamic refutation of an interpretation of quantum mechanics.

3 Digital substrate transfer

The March chapter said digital transfer extends the operating window by trading efficiency for replaceability: hardware can be replaced where tissue cannot, at a thousandfold higher cost per bit (V5-L71). Whole-brain emulation is a research proposal that needs a sufficiently informative description of a brain, a validated dynamical model and a physical implementation. Reproducing behavior, preserving memories and establishing continuity of personal experience are different questions, and thermodynamics alone answers none of them [I23].

Replaceable components and transferable records may change the reliability and maintenance options of a digital system. They do not establish that a person has transferred, that replacement is indefinitely reliable, or that the biological alternative is wholly unrepairable, and any implementation would still need power, a heat sink, materials, error management and an operating environment. The comparison of about 10^6 for biology against 10^9 for silicon is withdrawn as a universal ranking, as in Volume 4. A synaptic event, an arithmetic instruction, a token of text and a restored memory bit are not interchangeable units, and no thousandfold penalty for an uploaded person follows from dividing them.

The March chapter saw neuromorphic computing closing the gap in the framework's favor. It remains a relevant engineering direction, with its results scoped. The March text credited the first language model on Loihi 2, at half the energy of a GPU system, to Eshraghian and colleagues (V5-L72). Abreu and colleagues adapted a 370-million-parameter language-model architecture to Loihi 2; the headline energy comparison used preliminary estimates, and the paper reports multi-chip limitations and omitted embedding stages. It is evidence for one co-design investigation, not a universal advantage or biological equivalence [I24].

The March chapter cited Hala Point at owl-brain scale, fifty times faster at a hundredth of the energy, and SpiNNaker2's efficiency multipliers at Sandia (V5-L73). Intel's announcement describes a large research system with workload-dependent claims, and Sandia reports deployments of both Loihi 2 and SpiNNaker2. Artificial-neuron counts indicate implementation scale; they do not equate a system to an

owl's brain or to the energetic cost of its cognition. Selected-workload multipliers should not migrate into the framework's relational comparisons [I25, I26].

The March text also put neuromorphic hardware at 20–50 picojoules per synaptic operation, within five to fifty times of biology's 1–10 femtojoules, and projected the thousandfold gap narrowing to tenfold (V5-L74). The arithmetic was wrong: those ranges give ratios from 2,000 to 50,000. Correct arithmetic would still not validate the inputs or make the operations equivalent, so the ranges stay only in the audit calculation, not as a biological benchmark [I-CALC-05].

The useful question is how a specified implementation performs a specified task, at stated accuracy, latency, reliability and accounting boundary. Better results could change an engineering tradeoff. They would not resolve the identity question behind substrate transfer.

4 Reversible computing

The March chapter called reversible computing the most theoretically interesting strategy, and it changes the argument more deeply than the March text allowed. Bennett showed how computations can be embedded in a logically reversible process that retains enough information to recover the inputs and uncomputes its intermediate records. Logical reversibility removes the need to treat every logical step as erasing one unknown bit; it does not promise zero dissipation in a real device running at finite speed [I13].

The March chapter exempted the transducer: its three stages are each logically irreversible, because “a filter that does not discard is not a filter,” so reversible hardware can only shrink the distance above the Landauer tax (V5-L75). A simple construction shows why the stages are not automatic exceptions. For a deterministic classical function f, the map:

$$(x, y) \rightarrow (x, y \oplus f(x))$$

is reversible: with x retained, applying it again recovers y. Starting from y = 0 yields a copy of the result while preserving x. The output alone may discard distinctions, but the larger physical implementation need not erase them at that step, and this holds for a formally specified filter as for any other function [I-CALC-06]. The March slogan confuses discarding distinctions from an output with destroying every physical record of the input.

A finite device used repeatedly cannot assume unlimited blank memory or free restoration of its auxiliaries; eventually its storage, output handling, environment and reuse conditions must enter the account. A reset that meets the usual Landauer conditions keeps its bound, and a record that is known or correlated with accessible information can have a different reset cost. The cost belongs to the specified process and cycle [I12–I14].

The March chapter cited Vaire Computing's Ice River prototype, recovering 40–70 percent of computational energy, with a projected four-thousandfold gain and commercial chips by 2027, and Frank and colleagues' theory confirming that reversible architectures circumvent the Landauer limit (V5-L76). Frank and Shukla develop a nonequilibrium quantum-thermodynamic approach to classical reversible computing that supports studying implementations and their speed–dissipation tradeoffs; it does not

certify a commercial forecast [I27]. The Ice River percentages, projection and timetable are not retained as verified results; the primary evidence checked for the second edition did not establish them.

The March chapter concluded that reversible computing touches only the surface's amplification constraint, so non-compensability holds (V5-L77). The proposed three-constraint relational efficiency surface cannot be rescued by declaring two constraints immune to reversible hardware: no validated relational semantic-efficiency ceiling or non-compensability theorem has been derived here. It is a reason to specify hardware, encoding, task performance and the semantic-information model more carefully, not to preserve an unsupported equation.

5 Longevity escape velocity

The March chapter called longevity escape velocity the most promising approach for extending a biological transducer: degradation is entropy accumulation, repair is local entropy reduction that locally violates the second law while satisfying it globally, and every repair pays its own Landauer tax (V5-L78). Longevity escape velocity proposes that successive improvements in intervention could extend remaining life faster than elapsed time reduces it. It is a conjecture about the pace and efficacy of future biomedical progress, not an observed condition or a thermodynamic theorem. Population evidence about recent lifespan trends cannot prove every future intervention must fail, and neither side supplies a timetable for indefinite survival [I28, I29].

Repair sustains a living system by consuming resources and exchanging heat and matter with the environment. That is compatible with the second law locally as well as globally; an open subsystem that maintains organization violates nothing. Aging is not one measured scalar of “entropy accumulation”: oxidative damage, altered gene regulation, protein damage and loss of function involve different mechanisms. And “one DNA repair” or “one refolding” is not, by its name, a reset of one unbiased bit; no fixed Landauer tax per molecular correction is established [I12, I33].

If effective repair can extend a person's healthy operating window, it is worth understanding without being renamed an escape from physics. Whether a particular intervention is safe and effective is a biomedical question, not this framework's. This chapter offers no treatment recommendation and does not rank the proposal as the most promising route.

The March section ended: on biological timescales of centuries, millennia or millions of years, the universal budget is no constraint, and on cosmological timescales it is the only one (V5-L79). At human timescales the operative constraints include biological feasibility, resources, reliable care and the environment. At remote times those constraints are joined, not replaced, by questions of accessible matter, free-energy gradients, heat disposal and the future spacetime. No calculation here makes the cosmological bound the sole remaining obstacle or guarantees any span of operation.

6 Cosmic futures as conditions

The March chapter revisited its three scenarios: under ΛCDM the budget persists for 10^{100} years and more, so nothing on a civilizational timescale is constrained; the Big Rip shreds every transducer; and fading Λ is the most favorable scenario, the one DESI slightly favors (V5-L80). Chapter 3's scenarios are

conditional backgrounds, not three measured futures. A future event horizon exists when $\int_t^{t_{max}} c\, dt'/a(t')$ is finite, and present acceleration alone does not fix that integral.

Under a persistent positive cosmological constant, late-time spacetime approaches de Sitter expansion: the event horizon's proper radius tends toward a constant while its comoving radius shrinks. That does not mean every notion of observable volume or accessible entropy decreases, and a finite horizon entropy does not specify how long a civilization can operate. Usable work, resource capture, isolation of bound structures and heat sinks need their own analysis, and a black-hole evaporation timescale of 10^{100} years guarantees no operating budget that long.

In models with sufficiently persistent phantom behavior, a finite-time Big Rip can destroy bound structures and would constrain every implementation considered here. A transient crossing or a fitted present-day value does not establish that fate. If dark energy fades so that the horizon integral diverges, there is no permanent event horizon of that kind, but it does not follow that all matter becomes accessible, resources stay constant or computation becomes unlimited. The second law alone does not prove the universe has a finite resource total.

Chapter 3's evidence does not make any of these the framework's favored fate. The attraction of a longer operating window is understandable; it should not be promoted into a claim about dark energy.

7 The framework's relationship to entropy

The March chapter's last section began: the framework's relationship to entropy is not adversarial. That stands. Its next sentences do not: the framework is an entropy theory, the Trinket is an entropy token, love is an entropy operation (V5-L81). The question can remain without them: what happens when physical resources flow through a system that attends and responds to another system? It is worth asking without declaring love a measured thermodynamic operation.

The March chapter called the founding line not a problem to solve but the physics to understand: the surplus is irreducible, every connection pays more than it buys, and the waste is the irreversible record, the arrow of time applied to love (V5-L82). The line remains part of the project's language **[Analogical]**. As a literary prompt, it directs attention to investment, maintenance and connection. As a physical equality or inequality, it is not established. An act of care need not lower a defined system entropy, an entropy decrease need not quantify its benefit, and a physical cost does not set the worth of what happened. The second law requires a proper balance, not the slogan that every connection pays more than it buys. In the reversible limit total entropy production can approach zero, and calling the remainder “waste” adds a performance criterion physics does not choose.

The March chapter added that technology may change the price, but the Landauer floor, the semantic-efficiency ceiling and the second law do not (V5-L83). Technology may change specific costs and capabilities. The proposed relational semantic-efficiency ceiling has not been established as a fixed physical constraint. It also does not follow that people owe one another maximal efficiency, that greater sacrifice proves greater care, or that prolonging operation is the only meaningful goal. The framework can study resources while leaving those judgments visible as ethical choices.

What this chapter now claims

Four proposals were examined without treating them as interchangeable technologies. Many-worlds supplies no demonstrated additional resource account. Digital transfer remains hypothetical and cannot inherit a universal biological-to-silicon ratio. Reversible computing can change which erasures a computation requires, so the unavoidable-stage-tax argument fails. Longevity escape velocity remains an unverified forecast about intervention and progress. Neither a guarantee nor a thermodynamic prohibition of indefinite survival follows.

The March chapter closed: the budget cannot be beaten, the framework does not try, the surplus is irreducible, the cost is real, the connection is what the cost buys. The corrected close keeps the Principal's words and changes what they mean. “I can't beat entropy” can be a commitment to discipline: name the resource, the boundary and the task. It need not end the inquiry into what can be repaired, preserved or made possible within them.

Chapter 6: What the Ledger Shows

The Cosmological Budget and the Framework It Questions

Status: A synthesis of the preceding chapters and of Volumes 1–4. This chapter does not independently validate those volumes or the wider framework. It separates physical constraints from the relational interpretations that remain to be tested.

1 What this volume did

The March chapter summed up the volume as a set of findings about the relational economy: an upper bound proved by operator algebra, a current state of 10^{104} bits against 10^{122} bits of capacity, a shrinking accessible region, a dominant reservoir whose evaporation is Landauer erasure, and an information architecture in which scrambling destroys meaning while preserving existence. The economy's relational content, it said, is a tiny fraction of that budget, but the fraction that flows through transducers directing entropy at each other (V5-L84).

The volume began with that strong image, every act of connection drawing on the universe's remaining entropy budget, and the revised account cannot keep it as a quantitative result. The inventories concern specified regions, the bounds belong to specified settings, and the resources available to a system depend on its environment and possible operations. That changes the argument, not just its tone. There is no measured universal balance from which a conversation subtracts its price, and no established conversion from affection, grief or reciprocity to a cosmological entropy debit. What the volume identifies instead are physical questions a relational account must answer locally before drawing cosmological conclusions.

The distinction between a result and its application runs through every chapter. A mathematical construction for a de Sitter static patch is not an unconditional bound for every region in the actual universe. A fitted dark-energy history is not a measurement of the remote future. A theoretical connection between Hawking evaporation and Landauer's principle is not an experiment on an astrophysical black hole. Chapters 2–4 keep each result without its extra conclusions.

2 What follows for Axiom 0

The March chapter called this volume the empirical grounding of the Axiom 0 derivation: substrate neutrality follows from Landauer's principle applied to a shared budget, the ceiling is proved and the principle's universality confirmed at every scale (V5-L85). That claim is withdrawn. Sharing physical laws does not establish equal relational capacities, equivalent internal experience, equal computational costs or a universal relational currency. Different implementations can obey the same laws while differing in dynamics, resources and capabilities.

Axiom 0 can remain a methodological commitment, as in Volume 1: do not settle a claim about a system solely by naming its material. A proposed comparison should specify the task, the relevant observables, the resource boundary and the evidence that would distinguish its alternatives. The commitment does not guarantee that two substrates will prove equivalent once examined.

Landauer's principle constrains a defined information-processing operation under stated conditions. It does not certify that selection, compression and structuring are three obligatory erasures in every relational act, or make the transducer the unique architecture compatible with thermodynamics. Volume 1 Chapter 6 and Chapter 5 here keep reversible implementation as part of the question, not an exception ruled out by vocabulary.

The separate Axiom 0 derivation, WP-19 and the cosmological session findings remain dependent documents that need their own revision. This volume withdraws its claims of having proved them; it does not silently edit or certify them.

3 The five volumes after correction

The March chapter read the five volumes as one argument from the bottom up. The budget exists and has a proven maximum; all relational processing draws on it in one currency; relational systems arise because dissipative structures are favored; substrates differ by a thousandfold on the same budget; and the body pays in cortisol, immune function, heart-rate variability and aging, with grief a measurable thermodynamic event. Read in either direction, it said, the argument arrives at the founding line (V5-L86).

Each link of that chain has been withdrawn or narrowed in its own volume. The corrected volumes read like this:

- **Volume 1** asks how relational activities are physically implemented and accounted for. Its substrate and Trinket vocabulary no longer names a calibrated thermodynamic currency, and its observation distinction separates expenditure from registration and outcome without making every act of care a measured entropy inequality.
- **Volume 2** asks what bodies undergo in connection, conflict and loss. Physiological and health findings keep their actual variables, populations and designs; cortisol, heart-rate variability, inflammation and mortality associations are not alternative units of entropy, and grief is not a thermodynamic event because a risk ratio sits beside a cosmological formula.
- **Volume 3** asks what physical constraints and history contribute to the emergence of complex systems. A selected sequence from atoms to AI is no longer evidence of a universal rise in entropy production or a general preference for relational complexity.
- **Volume 4** asks how implementation affects resource use and relational functioning. It withdraws the efficiency surface as a universal bound, its mortality calibration and the fixed thousandfold biological advantage.
- **Volume 5** supplies cosmological context and conditions. It does not restore the withdrawn claims by setting them beneath a larger ceiling.

The series can be read in either direction as an inquiry across scales. It is not yet a chain of deductions from a cosmic entropy inventory to the meaning of a relationship.

4 What the expansion added and what needed correction

The March chapter listed four ways the expansion deepened the volume: the numbers were current again, the ceiling had moved from analogy to proof, the hard limit had become a variable under strengthening DESI evidence, and Landauer's principle now spanned the full range of scales, with the transducer's scale invariance experimentally verified at both extremes (V5-L87).

The expansion did add substantial literature to the earlier short volume, and that breadth is valuable when references keep their actual identities, versions and scope. A later citation is not automatically a corrected premise. Egan and Lineweaver's values are historical estimates with distinct boundaries, and the later census appears with its correct authors and publication history, its internal numerical disagreements not silently repaired or presented as a definitive total [C01, C02]. The horizon discussion separates the energy-radius bound, the horizon area relation and the de Sitter construction; the dark-energy discussion keeps reported constraints tied to their datasets and models, not to a choice among promised endings [C08, C20–C22]. The information discussion separates global unitary dynamics from a usable record, and quantum scrambling from the Kolchinsky–Wolpert intervention.

The March statement that the transducer's scale invariance was experimentally verified at the black-hole extreme is removed. The Hawking–Landauer connection is theoretical, and laboratory information-thermodynamics results have their own systems and protocols; they do not close an experimental chain from biological relational processing to cosmology.

5 What remains worth pursuing

The March chapter's last section listed what did not change: the instruments still work, the efficiency surface still governs, the BSB still applies, the SupoRel flags still fire, and the seven categorical gaps apply to this volume as rigorously as to any other (V5-L88). Claims that the instruments are validated and that the efficiency surface is a governing universal bound do not survive; the conceptual tools and comparison framework remain proposals requiring definitions and evidence. The gaps and cautions do, as editorial questions: the cosmological budget permits relational systems but does not require them; it does not specify which form; the cosmological ceiling and the body's costs sit at different scales; and even a demonstrated constraint would carry no normative force. They do not become validated instruments by surviving a revision. Cosmology does not rank relationships morally, and a physical explanation that invokes no purpose does not prove every philosophical account of purpose false.

The framework's strength can lie in the questions it makes explicit. What resources support a given act? Which signal is produced, which receiver can access it, and what follows? Which part of an apparent cost belongs to the task, its implementation, its infrastructure or the choice of comparison? A testable proposal would identify a system boundary and timescale, keep energy, entropy and information apart, and define relational outcomes independently of the physical cost it seeks to explain, with competing explanations and an observation that would count against it. A useful result might be local and conditional. It need not apply to every substrate or reproduce the history of the universe.

The founding line, “love reduces the entropy of the system and spends more than it saves,” remains an Analogical motivating statement of the project's intuition **[Analogical]**. Without a specified system,

entropy measure and complete balance, it is not a thermodynamic theorem. It can motivate the investigation without deciding its result.

The March chapter said the framework is not a cosmology but a relational theory grounded in cosmological physics (V5-L89). The first half stands. The second claims more than the volume can support: cosmology bounds what can be asked, not what the answer is. The March volume closed: “The Trinket economy is a rounding error on the universal ledger. The rounding error is where connection lives.” No measured universal ledger pricing relational acts is established here, so no such rounding error has been calculated. Connection lives where it always did, in the particular systems, signals and receivers this volume has been asking about, and it remains worth investigating even where the proposed ledger cannot yet price it.

Volume 5 correction ledger

The ledger traces 89 selected March claims in Volume 5. By this edition's classification of the second edition's treatment, 28 were withdrawn, 54 narrowed, 5 corrected and 2 kept. “Corrected” marks a figure or attribution fixed while the claim's role in the argument is unchanged. It is not an exhaustive inventory, and it makes no new scientific decisions.

March locations refer to the preserved Volume 5 page on suposystem.ai. Second-edition (2E) locations use the October 2026 Volume 5 headings and its C and I labels.

ID	March claim (Volume 5 location)	2E disposition	2E location	Basis
V5-L01	Ch 1 §1: the ledger the framework describes is the universe's entropy budget.	Withdrawn; the ledger kept as an image	Ch 1 §1	A conversation, a star and a horizon do not become entries in one spendable balance.
V5-L02	Ch 1 §2, Ch 2 §1: current entropy about 10^{104} bits; horizon about 10^{122} bits.	Narrowed: historical estimates in k_B units	Ch 1 §2; Ch 2 §1 [C01]	Egan and Lineweaver report k_B units; bits need the factor ln 2; the estimates are model-dependent (as V1-L06).
V5-L03	Ch 1 §2: the eighteen-order gap is the universe's remaining capacity for structure, complexity and order: the budget.	Withdrawn	Ch 1 §2; Ch 2 §3	Different regions; an entropy difference does not measure available work (as V1-L04).
V5-L04	Ch 1 §2: the Entropy Token Substrate is this gap; every Trinket draws from the same reservoir.	Withdrawn	Ch 1 §2	The contrast establishes no accessible energy, number of relationships or operating lifetime.
V5-L05	Ch 1 status: the cosmological entropy budget is Established.	Narrowed	Ch 1 status	Estimates have specified boundaries and assumptions; the relational application is a proposal.
V5-L06	Ch 2 status: Established throughout; the numbers are measured and published, and the physics is settled.	Narrowed	Ch 2 status	The quantities range from model-based inferences to semiclassical results to proposals.
V5-L07	Ch 2 §1: stellar-mass black holes about 10^{78} k_B; CMB about 10^{88} k_B.	Corrected	Ch 2 §1 [C01]	In the 2010 source: stellar black holes 5.9×10^{97}, CMB photons 5.40×10^{89}; the March figures were not the source's totals.
V5-L08	Ch 2 §1: Profumo and colleagues' census confirms the standard numbers.	Narrowed	Ch 2 §1 [C02]	It broadens the inventory; its black-hole results are not reconciled internally; its dark-sector values are model explorations.
V5-L09	Ch 2 §1: merger entropy passed the CMB near $z \approx 12$, so gravitational processes dominated before the first galaxies.	Narrowed	Ch 2 §1 [C03]	A population-model result, not an observation; merger entropy can double count remnants.
V5-L10	Ch 2 §1: “when the framework says one ledger, this is the ledger”; every Trinket draws from the reservoir that fusion and accretion draw from.	Withdrawn	Ch 2 §1; What this chapter supports	The ledger is an accounting ambition, not a discovered universal account.
V5-L11	Ch 2 §1: the human contribution is a rounding error; relational entropy matters in kind, as the fraction directed between transducers.	Withdrawn	Ch 2 §1	No census isolates a relational-entropy fraction; accumulated entropy and production rate differ.
V5-L12	Ch 2 §2: the Bekenstein–Hawking bound applied to the cosmic event horizon is the universe's fixed maximum, about 2.6×10^{122} k_B.	Narrowed	Ch 2 §2 [C04–C06]	The Bekenstein expression, the area law and de Sitter horizon entropy are separate results with separate conditions.

ID	March claim (Volume 5 location)	2E disposition	2E location	Basis
V5-L13	Ch 2 §2: Buoninfante and colleagues show the bound is essentially the uncertainty principle, tightened near the Planck scale.	Narrowed	Ch 2 §2 [C09]	The link rests on thermodynamic assumptions; corrections depend on the deformation chosen.
V5-L14	Ch 2 §2: Chandrasekaran, Longo, Penington and Witten prove the 10^{122} ceiling; “the bound is not heuristic. It is proven.”	Narrowed	Ch 2 §2 [C08]	A Type II_1 result within a semiclassical static-patch construction, not a universal numerical ceiling.
V5-L15	Ch 2 §2: holography works only in 3+1 dimensions, so the framework depends on three spatial dimensions (Volovik).	Narrowed	Ch 2 §2 [C10]	The dimensional correspondence is a feature of that construction.
V5-L16	Ch 2 §2: no infinite relational capacity anywhere; every substrate runs within a finite local budget nested in the universal one, with a maximum fixed by proof.	Withdrawn	Ch 2 §2	No derivation gives a universal amount of connection a region can sustain.
V5-L17	Ch 2 §3: the gap is the remaining budget, a ratio near 10^{18}, depleted by every process and certain only to shrink.	Withdrawn	Ch 2 §3 [C05, C06, C11]	The ratio, about 8.4×10^{17}, compares different boundaries; the generalized second law does not make the difference shrink.
V5-L18	Ch 2 §3: the gap is the remaining free energy for every irreversible process; dark-sector scenarios could close it.	Withdrawn	Ch 2 §3 [C11, C02]	An entropy difference is in J/K, free energy in J; no temperature or extraction protocol is supplied.
V5-L19	Ch 2 §3: heat death ends the Trinket economy, on timescales from 10^{100} years to effectively infinite.	Narrowed	Ch 2 §3 [C25]	A conditional future; 10^{100} years for an assumed enormous black hole is not a measured date.
V5-L20	Ch 2 §4: the arrow of time is the direction of entropy increase, and the second law breaks the symmetry of all fundamental equations.	Narrowed	Ch 2 §4 [C11, C12]	Irreversibility is statistical; time-reversal violation is observed in B mesons; initial conditions and coarse-graining matter.
V5-L21	Ch 2 §4: the Past Hypothesis as Carroll's Thermodynamic Past Hypothesis.	Narrowed; attribution corrected	Ch 2 §4 [C13, C14]	A posited boundary condition; Carroll and Chen's explanation is one proposal.
V5-L22	Ch 2 §4: the Entanglement Past Hypothesis gives a decoherent arrow beyond heat death, decoherence as a Level 0 transducer, and Trinket irreversibility rooted in entanglement.	Narrowed: a research proposal; transducer links withdrawn	Ch 2 §4 [C14]	Unitary evolution does not raise fine-grained entropy; subsystem mixing is a different statement.
V5-L23	Ch 2 §4: the Wentaculus writes the arrow into the quantum state of the universe.	Narrowed	Ch 2 §4 [C15]	It changes the representation; it does not establish the boundary condition empirically.
V5-L24	Ch 2 §4: the transducer's three stages are logically irreversible; the founding line is the arrow of time for relational systems.	Withdrawn	Ch 2 §4 [C31–C33]	As V1-L17 and V1-L34; stage labels fix no erased bits.
V5-L25	Ch 2 §5: gravitational potential energy released in collapse powers nuclear fusion.	Corrected	Ch 2 §5 [C16]	Fusion energy comes from nuclear binding-energy differences; gravity heats and enables.
V5-L26	Ch 2 §5: the Weyl curvature hypothesis; the initial state was low-entropy by some measure.	Narrowed	Ch 2 §5	Exact FLRW has vanishing Weyl curvature; no unique Weyl-based entropy measure is adopted.
V5-L27	Ch 2 §5: each symmetry-breaking event increased entropy as a unified force separated.	Withdrawn	Ch 2 §5 [C17]	Symmetry breaking does not by itself raise entropy; the electroweak change is a crossover; unification is a hypothesis.

ID	March claim (Volume 5 location)	2E disposition	2E location	Basis
V5-L28	Ch 2 §5: the budget is dual-sourced, and the relational economy lies downstream of two reservoirs (Supported).	Withdrawn as a theorem; the historical question kept	Ch 2 §5	Two quantitative reservoirs would need definitions, a common boundary and non-overlap.
V5-L29	Ch 3 status: dark matter exists, the cosmological event horizon is real, and the Bekenstein bound applies to all regions (Established).	Narrowed	Ch 3 status	Strong gravitational evidence for dark matter; horizon statements specify a model; bounds carry conditions.
V5-L30	Ch 3 §1: 95% of the universe is dark, signals in no channel our transducers read, and the relational economy runs on the remaining 5%.	Narrowed	Ch 3 §1 [C18]	ΛCDM present energy-density fractions, not entropy or relational activity; dark matter is detected gravitationally.
V5-L31	Ch 3 §2: Finding A3: dark matter “was there” or “was produced”; primordial black holes form before any thermal process.	Narrowed and corrected	Ch 3 §2 [C19, C34, C35]	Production mechanisms within a history, not kinds of initial substance; primordial black holes are formed objects.
V5-L32	Ch 3 §2: a primordial-black-hole fraction could put dark matter's entropy near 10^{122} k_B, most of the entropy the economy sits within.	Narrowed	Ch 3 §2 [C02]	Conditional scenarios that need a mass function, abundance constraints and region.
V5-L33	Ch 3 §2: DFL-001: relational opacity is not absence; our transducers lack the filter geometry to read dark matter, or AI internal states.	Narrowed: the caution kept	Ch 3 §2	Nondetection is not absence, and failure to exclude is not evidence; the uncertainty is physical.
V5-L34	Ch 3 §2: the concentrated ETS question: a substrate that is entropy, with a larger share of the budget.	Narrowed to a physical question	Ch 3 §2	Entropy is assigned to a state under a description, not a substance.
V5-L35	Ch 3 §3: entities beyond each other's event horizon can never exchange signals; the observable universe shrinks in comoving coordinates.	Narrowed and corrected	Ch 3 §3 [C23, C01, C02]	Particle, event and Hubble radii differ; old light still arrives; the comoving particle horizon grows toward a limit.
V5-L36	Ch 3 §3: DESI's evidence for dynamical dark energy strengthened over two releases, with clear preference for phantom crossing.	Narrowed	Ch 3 §4 [C20–C22]	Per-analysis significances that did not rise at every step; no mechanism or fate is selected.
V5-L37	Ch 3 §3: the framework's claims depend on the endpoint, because dark energy sets the Entropy Token Substrate's total budget.	Withdrawn	Ch 3 §3	Follows V5-L04; causal constraints do not price a relational transaction.
V5-L38	Ch 3 §3: under ΛCDM, 10^{122} k_B is the most the universe will hold, and every transaction draws on a budget that will be exhausted.	Narrowed	Ch 3 §5 [C06, C23]	The present horizon evolves toward a de Sitter limit; horizon entropy is not a target for interior matter.
V5-L39	Ch 3 §3: the Big Rip tears spacetime apart and violates the generalized second law through a shrinking horizon.	Narrowed	Ch 3 §5 [C24]	Constant $w < -1$ can give a finite-time rip; a transient crossing does not; area alone does not diagnose a violation.
V5-L40	Ch 3 §3: fading Λ lifts the ceiling; distant transactions become merely exponentially expensive.	Narrowed	Ch 3 §5 [C23]	No event horizon of that kind, but entropy constraints remain; no universal cost law is derived.
V5-L41	Ch 3 §3: the founding line holds in all three scenarios.	Withdrawn as a physical claim	Ch 3 §5	The second law holds in all three; the founding line is an Analogical image, not that law.
V5-L42	Ch 3 §3: the scenarios map onto eschatological archetypes because cosmic fate genuinely parallels eschatology.	Narrowed	Ch 3 §5	The associations are interpretations people make, not evidence about cosmology.

ID	March claim (Volume 5 location)	2E disposition	2E location	Basis
V5-L43	Ch 3 §4: a 10^9-solar-mass black hole holds about 10^{96} k_B; black holes are most of the budget.	Corrected	Ch 3 §6 [C05, C28]	About 1.05×10^{95} k_B for a nonrotating hole; populations need a mass distribution; an inventory is not a budget.
V5-L44	Ch 3 §4: the Page curve and island formula, resolved in 2019–2021, establish that infalling information is not destroyed.	Narrowed	Ch 3 §6 [C26, C27, C36]	Strong theoretical evidence in controlled models, not observation; turnover and growth are not universal.
V5-L45	Ch 3 §4: relational information entering a black hole is scrambled, not lost; the Trinket's irreversibility is about access; the recording persists.	Narrowed	Ch 3 §6; Ch 4	Formal preservation does not establish a semantic record's existence, location or recoverability.
V5-L46	Ch 3 §4: evaporation exactly saturates Landauer; black holes at 1×, biology at 10^6, silicon at 10^9; scale invariance confirmed.	Narrowed; substrate factors withdrawn	Ch 3 §6 [C28]	A theoretical identification for the entropy decrement; no ranking of implementations; not a test of scale invariance.
V5-L47	Ch 3 §4: Trivedi's cosmological information paradox; Landauer satisfied across eras, reversible where w crosses −1/3.	Narrowed	Ch 3 §6 [C29, C30]	Particular apparent-horizon constructions; no experimental exception; apparent and event horizons differ.
V5-L48	Ch 3 §4 SupoRel: information is preserved, access is not; the comfort is refused.	Kept as a caution; the preservation premise narrowed	Ch 3 §6; Ch 4 §7	Preservation is a conditional result for complete states, not a fact about a particular record.
V5-L49	Ch 3 §5: the economy runs on the visible minority, bounded by the dark majority; the budget is set by the whole.	Narrowed	Ch 3 §7	A conditional program; the budget framing does not survive.
V5-L50	Ch 4 status: Hawking radiation, the Page curve, Landauer and decoherence Established; islands, unitarity and quantum Darwinism Supported.	Narrowed	Ch 4 status [I01–I03, I08, I12]	Semiclassical prediction, model-based theoretical evidence and laboratory results each keep their own scope.
V5-L51	Ch 4 §1: the physics now strongly supports preservation; the only question is what preservation means.	Narrowed	Ch 4 §1 [I01–I03]	Major theoretical progress, but no observed decoder for a real black hole; unitarity holds within the description.
V5-L52	Ch 4 §2: scrambling spreads information across exponentially many degrees of freedom; recovery needs over half of all Hawking radiation.	Narrowed and corrected	Ch 4 §2 [I04, I05]	Hilbert-space dimension grows exponentially; recovery depends on model and control; complexity is not proof of impossibility.
V5-L53	Ch 4 §2: solar-mass evaporation in about 10^{67} years at 10^{-7} K; 10^9 solar masses in 10^{97} years; no instrument could ever retrieve the information.	Corrected	Ch 4 §2 [I01; I-CALC-01]	About 6.2×10^{-8} K and 2.1×10^{67} years; 2.1×10^{94} years for 10^9 solar masses, idealized; impossibility not shown.
V5-L54	Ch 4 §2: quantum scrambling is the Kolchinsky–Wolpert decorrelating intervention, which is the Shadow Economy.	Withdrawn	Ch 4 §2 [I06]	Different operations; a withheld message can keep strong correlations (as V1-L12).
V5-L55	Ch 4 §3: Trinket formation requires redundant environmental broadcast; the universe guarantees only global preservation.	Narrowed	Ch 4 §3 [I07, I08]	Redundancy aids many observers but is not necessary for every transmission; no Trinket threshold follows.
V5-L56	Ch 4 §3: Zhu and colleagues made the first experimental observation of quantum Darwinism in superconducting circuits.	Narrowed	Ch 4 §3 [I08]	Evidence for signatures within the specified superconducting-circuit preparation; platform-specific priority is not adjudicated here.

ID	March claim (Volume 5 location)	2E disposition	2E location	Basis
V5-L57	Ch 4 §4: the Bekenstein–Hawking bound limits any region's information; zero-bit resources transcend it because it limits decoding, not encoding.	Narrowed	Ch 4 §4 [I09, I10]	Bounds need a specified task and resources; encoder and decoder restrictions also constrain zero-bit capacity.
V5-L58	Ch 4 §5: Landauer at every scale: every irreversible bit operation dissipates at least kT ln 2; experiments now reach the bound.	Narrowed	Ch 4 §5 [I11–I18]	A specified reset under stated conditions; equality is an ideal limit; the experiments are complementary, not a survey.
V5-L59	Ch 4 §5: biology at about 10^6 and silicon at 10^9 times the floor, formalized by the efficiency surface.	Withdrawn	Ch 4 §5	As V4-L07 and V4-L15.
V5-L60	Ch 4 §5: the chain is complete; Landauer is the invariant and the transducer the structure that satisfies it, grounding scale invariance.	Withdrawn	Ch 4 §5 [I19, I20, I31, I34]	Shared laws constrain a future model; stage labels identify no erasures.
V5-L61	Ch 4 §6: Layer A is permanently recorded on the universal ledger; meaning is transient; unrecorded neural states scramble almost instantly.	Withdrawn	Ch 4 §6	Entropy production is not an archive; recognition can persist; no single scrambling timescale exists.
V5-L62	Ch 4 §6: the four populations of the gap are cosmological information states.	Narrowed	Ch 4 §6	They remain human examples, not quantum states or entropy values.
V5-L63	Ch 4 §7: “Love is never truly lost”; the comfort is illusory.	Narrowed	Ch 4 §7	The cited physics does not warrant the reassurance, and it does not disprove every account of survival either.
V5-L64	Ch 4 §7: “The universe remembers every act of love” is technically true but spiritually misleading.	Narrowed	Ch 4 §7	A metaphor, not a technical consequence of unitarity.
V5-L65	Ch 4 §7: meaning is not the universe's purpose; the universe spends entropy because the second law demands it.	Narrowed	Ch 4 §7	The second law does not command each process to produce entropy or measure an outcome's value.
V5-L66	Ch 4 §7: the SupoRel ruling: state the physics, name the comfort, show why it depends on an unsupported reading.	Kept	Ch 4 §7	Neither hope nor its rejection is an experimental result of black-hole physics.
V5-L67	Ch 5 status, §1: “I can't beat entropy” is correct; the second law is not an engineering challenge but the arrow of time.	Narrowed: kept as a refusal to expect operation outside thermodynamics	Ch 5 status, §1	The law constrains improvements; it does not forbid better devices, repair or use of resources.
V5-L68	Ch 5 §1: every strategy operates within the entropy budget; the budget is not beaten, only spent differently.	Withdrawn	Ch 5 §1 [I12, I33]	No fixed cosmic spending account; open systems need not gain entropy; total production can approach zero.
V5-L69	Ch 5 §2: many-worlds multiplies independently depleting budgets that cannot share resources.	Narrowed	Ch 5 §2 [I21]	Branch descriptions need no new energy accounts; many-worlds is not a fuel or transfer mechanism.
V5-L70	Ch 5 §2: branching irreversibly produces entanglement entropy, making many-worlds worse than neutral.	Withdrawn	Ch 5 §2 [I22; I-CALC-04]	A global pure state stays pure under unitary evolution; subsystem entanglement can rise and fall reversibly.
V5-L71	Ch 5 §3: digital transfer trades efficiency for replaceability, paying about a thousand times more per bit.	Withdrawn; transfer kept as a hypothetical	Ch 5 §3 [I23]	No universal substrate ranking; behavior, memory and continuity of experience are separate questions.
V5-L72	Ch 5 §3: the first language model on Loihi 2 ran at half a GPU system's energy (credited to Eshraghian and colleagues).	Narrowed; attribution corrected	Ch 5 §3 [I24]	Abreu and colleagues; preliminary energy estimates, multi-chip limits and omitted stages.

ID	March claim (Volume 5 location)	2E disposition	2E location	Basis
V5-L73	Ch 5 §3: Hala Point at owl-brain scale, fifty times faster at a hundredth of the energy; SpiNNaker2's multipliers.	Narrowed	Ch 5 §3 [I25, I26]	Announcements with workload-dependent claims; neuron counts do not equate a system to a brain.
V5-L74	Ch 5 §3: 20–50 pJ per synaptic operation is within 5–50 times of biology's 1–10 fJ; the thousandfold gap narrows toward tenfold.	Corrected; projection withdrawn	Ch 5 §3 [I-CALC-05]	The ratios are 2,000 to 50,000; the inputs are not validated as equivalent operations.
V5-L75	Ch 5 §4: the transducer's stages are logically irreversible; “a filter that does not discard is not a filter.”	Withdrawn	Ch 5 §4 [I13; I-CALC-06]	Reversible embedding keeps the input; discarding from an output is not erasing the physical record.
V5-L76	Ch 5 §4: Ice River recovers 40–70% of energy, with a projected four-thousandfold gain and chips by 2027; theory confirms reversible circumvention of Landauer.	Narrowed; Vaire figures not retained	Ch 5 §4 [I27]	Frank and Shukla support studying implementations; the commercial figures were not established by checked evidence.
V5-L77	Ch 5 §4: reversible computing affects only the amplification constraint, so non-compensability holds.	Withdrawn	Ch 5 §4	The proposed relational efficiency surface is not established as a universal bound, and no validated non-compensability theorem has been derived here (as V4-L18).
V5-L78	Ch 5 §5: longevity escape velocity is the most promising approach; repair locally violates the second law; every repair pays a Landauer tax.	Narrowed and corrected	Ch 5 §5 [I28, I29, I12, I33]	A conjecture about progress; open systems violate nothing locally; aging is not one scalar; no fixed tax per repair.
V5-L79	Ch 5 §5: the universal budget is no constraint on biological timescales and the only constraint on cosmological ones.	Withdrawn	Ch 5 §5	Human-scale constraints are joined, not replaced, at remote times; no span of operation is guaranteed.
V5-L80	Ch 5 §6: under ΛCDM the budget lasts beyond 10^{100} years; the Big Rip shreds every transducer; fading Λ is most favorable and slightly favored by DESI.	Narrowed	Ch 5 §6	Conditional backgrounds; an evaporation timescale guarantees no operating budget; DESI favors no endpoint.
V5-L81	Ch 5 §7: the framework is an entropy theory; the Trinket is an entropy token; love is an entropy operation.	Withdrawn	Ch 5 §7	As V1-L03 and V1-L14; the question survives without the identities.
V5-L82	Ch 5 §7: the founding line is physics to understand; every connection pays more than it buys; the waste is the arrow of time applied to love.	Withdrawn as physics; kept as an Analogical prompt	Ch 5 §7	Total production can approach zero in the reversible limit; “waste” adds a criterion physics does not choose.
V5-L83	Ch 5 §7: technology may change the price, but the Landauer floor, the semantic-efficiency ceiling and the second law do not.	Narrowed	Ch 5 §7	No fixed physical ceiling on relational semantic efficiency is established here; cost does not set the worth of an act.
V5-L84	Ch 6 §1: the relational economy has a proven upper bound, a current state of 10^{104} against 10^{122} bits, a shrinking accessible region and an information architecture that preserves existence while destroying meaning.	Withdrawn as a summary	Ch 6 §1	Each element is narrowed or withdrawn in Chapters 2–4; no universal balance prices a conversation.
V5-L85	Ch 6 §2: this volume is the empirical grounding of the Axiom 0 derivation; the ceiling is proved and Landauer's universality confirmed.	Withdrawn; Axiom 0 kept as a methodological commitment	Ch 6 §2	As V1-L10; shared laws do not establish equal capacities, costs or a common currency.
V5-L86	Ch 6 §3: the five volumes form one argument, from the budget through one currency, favored emergence and a thousandfold advantage to grief as a measurable thermodynamic event.	Withdrawn; replaced by the five volumes after correction	Ch 6 §3	Each link is withdrawn or narrowed in its own volume; the series is an inquiry across scales, not a chain of deductions.

ID	March claim (Volume 5 location)	2E disposition	2E location	Basis
V5-L87	Ch 6 §4: the expansion made the numbers current, moved the ceiling to proof, made the hard limit a variable, and verified scale invariance at both extremes.	Narrowed; scale-invariance verification withdrawn	Ch 6 §4 [C01, C02, C08, C20–C22]	The census is historical and unreconciled; constructions are not unconditional bounds; the Hawking–Landauer link is theoretical.
V5-L88	Ch 6 §5: what did not change: the instruments work, the efficiency surface governs, the BSB applies, SupoRel fires, the seven gaps apply.	Narrowed: gaps and cautions kept as editorial questions	Ch 6 §5	Validated-instrument status and the governing universal-bound claim are withdrawn; the conceptual tools and comparison framework remain proposals.
V5-L89	Ch 6 §5: the framework is a relational theory grounded in cosmological physics; “the rounding error is where connection lives.”	Narrowed: “not a cosmology” kept	Ch 6 §5	Cosmology supplies constraints, not the relational answer; no measured universal ledger pricing relational acts is established here.

References and source apparatus

The C references, I notes and source-access record are inherited verbatim from the second edition's Volume 5 apparatus, except that four flattened mathematical spans are restored from its original equation markup. Group C serves Chapters 2 and 3; group I serves Chapters 4 and 5; the I-CALC notes record the calculations behind the corrected figures.

References for Chapters 2 and 3

Primary-source checks were performed on 28 October 2026. Version dates below refer to repository metadata, not regenerated HTML display dates. The source access notes below record the inspection limits and unresolved census discrepancy. A citation supports its stated physical result, not the relational framework.

C01. Egan, C. A., and Lineweaver, C. H. 2010. *A Larger Estimate of the Entropy of the Universe*. Astrophysical Journal 710, 1825–1834. arXiv 0909.3983v3. Historical inventories, Tables 1 and 2; distinct accounting boundaries.

C02. Profumo, S., Colombo-Murphy, L., Huckabee, G., Diaz Svensson, M., Garg, S., Kollipara, I., and Weber, A. 2025. *A New Census of the Universe's Entropy*. JCAP 09, 049. arXiv 2412.11282v2; publisher. Broadened census and hypothetical dark sectors; unreconciled black-hole table versus equation values.

C03. Chen, S., Jani, K., and Kephart, T. W. 2026. *Cosmological Budget of Entropy from Merging Black Holes*. arXiv 2601.13621v1, submitted 20 January. Population-model result, not a direct high-redshift entropy measurement.

C04. Bekenstein, J. D. 1981. *Universal upper bound on the entropy-to-energy ratio for bounded systems*. Physical Review D 23, 287–298. Primary article. Bounded-system entropy-to-energy result and its self-gravity assumptions.

C05. Bekenstein, J. D. 1973. *Black Holes and Entropy*. Physical Review D 7, 2333; Hawking, S. W. 1975. *Particle creation by black holes*. Communications in Mathematical Physics 43, 199–220. Historical primary pair underlying semiclassical black-hole entropy and temperature; not an evaporation experiment.

C06. Gibbons, G. W., and Hawking, S. W. 1977. *Cosmological event horizons, thermodynamics, and particle creation*. Physical Review D 15, 2738–2751. Cosmological horizons in the stated positive-Λ setting.

C07. Bousso, R. 1999. *A Covariant Entropy Conjecture*. arXiv hep-th/9905177; JHEP 07, 004. Entropy on suitable light sheets, not an unrestricted spacelike-volume rule.

C08. Chandrasekaran, V., Longo, R., Penington, G., and Witten, E. 2023. *An Algebra of Observables for de Sitter Space*. arXiv 2206.10780v5; JHEP 02, 082. Observer-dressed static-patch construction and generalized entropy, with an additive normalization constant.

C09. Buoninfante, L., Luciano, G. G., Petruzziello, L., and Scardigli, F. 2022. *Bekenstein bound and uncertainty relations*. arXiv 2009.12530v2; Physics Letters B 824, 136818. Conditional thermodynamic argument and deformation-dependent generalizations.

C10. Volovik, G. E. 2024. *Thermodynamics and decay of de Sitter vacuum*. arXiv 2312.02292v16; Symmetry 16, 763. Proposed local de Sitter thermodynamics; not universal dimensional necessity.

C11. Crooks, G. E. 1999. *The Entropy Production Fluctuation Theorem and the Nonequilibrium Work Relation for Free Energy Differences*. arXiv cond-mat/9901352v4; Physical Review E 60, 2721. Specified stochastic microscopically reversible dynamics and work/free-energy relations.

C12. Lees, J. P., et al., BABAR Collaboration. 2012. *Observation of Time-Reversal Violation in the B^0 Meson System*. arXiv 1207.5832; Physical Review Letters 109, 211801. Counterexample to universal microscopic time-reversal invariance.

C13. Carroll, S. M., and Chen, J. 2004. *Spontaneous Inflation and the Origin of the Arrow of Time*. arXiv hep-th/0410270v1. Proposed cosmological account, not a settled origin of initial conditions.

C14. Al-Khalili, J., and Chen, E. K. 2024. *The Decoherent Arrow of Time and the Entanglement Past Hypothesis*. arXiv 2405.03418v1; Foundations of Physics 54, 49. Low-entanglement boundary-condition proposal and distinctions between entropy notions.

C15. Chen, E. K. 2022. *The Wentaculus: Density Matrix Realism Meets the Arrow of Time*. arXiv 2211.03973v1. Initial Projection Hypothesis; this is the specific account used, not the manuscript's conflated publication-and-award description.

C16. Wallace, D. 2010. *Gravity, Entropy, and Cosmology: In Search of Clarity*. arXiv 0907.0659v1; British Journal for the Philosophy of Science 61, 513–540. Gravity's role distinguished from an entropy assigned to gravity.

C17. D'Onofrio, M., and Rummukainen, K. 2016. *The Standard Model cross-over on the lattice*. arXiv 1508.07161v1; Physical Review D 93, 025003. Standard Model electroweak crossover at the physical Higgs mass.

C18. Planck Collaboration, Aghanim, N., et al. 2020. *Planck 2018 results VI Cosmological parameters*. arXiv 1807.06209v4; Astronomy and Astrophysics 641, A6, with correction. Baseline ΛCDM density parameters, not entropy fractions.

C19. Carr, B. J., and Hawking, S. W. 1974. *Black Holes in the Early Universe*. Monthly Notices of the Royal Astronomical Society 168, 399–415. Early-universe collapse and radiation-era evolution; not prethermal pre-existence.

C20. DESI Collaboration, Adame, A. G., et al. 2024. *DESI 2024 VI Cosmological Constraints from the Measurements of Baryon Acoustic Oscillations*. arXiv 2404.03002v3, revised 4 November 2024. Dataset-dependent dark-energy model comparisons.

C21. DESI Collaboration, Abdul Karim, M., et al. 2025. *DESI DR2 Results II Measurements of Baryon Acoustic Oscillations and Cosmological Constraints*. arXiv 2503.14738v3, revised 9 October 2025. Section VII and Table 6; stated external datasets required.

C22. DESI Collaboration, Adame, A. G., et al. 2026. *DESI DR2 Results IV Alcock–Paczyński Measurements from the Lyman Alpha Forest and Cosmological Constraints*. arXiv 2607.27410v3, submitted 29 July, revised 4 August 2026. Section VI.4.1, Table 4 and updated external-data combinations. The collaboration's announcement is dated 30 July; the paper, not that announcement, supplies the quantitative citation.

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C24. Caldwell, R. R., Kamionkowski, M., and Weinberg, N. N. 2003. *Phantom Energy and Cosmic Doomsday*. arXiv astro-ph/0302506; Physical Review Letters 91, 071301. Conditional phantom-energy Big Rip model.

C25. Adams, F. C., and Laughlin, G. 1997. *A Dying Universe The Long Term Fate and Evolution of Astrophysical Objects*. arXiv astro-ph/9701131; Reviews of Modern Physics 69, 337–372. Conditional astrophysical futures, not a measured heat-death date.

C26. Almheiri, A., Engelhardt, N., Marolf, D., and Maxfield, H. 2019. *The entropy of bulk quantum fields and the entanglement wedge of an evaporating black hole*. arXiv 1905.08762v3; JHEP 12, 063. Two-dimensional model and quantum extremal surfaces.

C27. Penington, G. 2020. *Entanglement Wedge Reconstruction and the Information Paradox*. arXiv 1905.08255v3; JHEP 09, 002. AdS/CFT evaporation and reconstruction under stated assumptions.

C28. Cortês, M., and Liddle, A. R. 2024. *Hawking evaporation and the Landauer Principle*. arXiv 2407.08777v2, revised 12 August 2024. Section II theoretical Schwarzschild calculation; the prior V501 correction remains in force.

C29. Trivedi, O. 2024. *Landauer's principle and information at the cosmological horizon*. arXiv 2407.15231v3, revised 25 December 2024. Apparent-horizon construction and its interpretation, not experimental falsification of Landauer erasure.

C30. Odintsov, S. D., Paul, T., and SenGupta, S. 2025 version. *Natural validation of the second law of thermodynamics in cosmology*. arXiv 2409.05009v2, revised 4 February 2025. Apparent-horizon/matter-temperature model, not a universal horizon theorem.

C31. Bennett, C. H. 1973. *Logical Reversibility of Computation*. IBM Journal of Research and Development 17, 525–532. Reversible computation; no mandatory cost for each cognitive label.

C32. Landauer, R. 1961. *Irreversibility and Heat Generation in the Computing Process*. IBM Journal of Research and Development 5, 183–191. Specified erasure, not a universal information-processing toll.

C33. Reeb, D., and Wolf, M. M. 2014. *An improved Landauer Principle with finite-size corrections*. arXiv 1306.4352v3; New Journal of Physics 16, 103011. Explicit reservoir and correlation assumptions.

C34. Preskill, J., Wise, M. B., and Wilczek, F. 1983. *Cosmology of the invisible axion*. Physics Letters B 120, 127–132. Nonthermal coherent-field production; not evidence that axions constitute dark matter.

C35. Gondolo, P., and Gelmini, G. 1991. *Cosmic abundances of stable particles Improved analysis*. Nuclear Physics B 360, 145–179. Thermal relic-abundance calculation; primary full text not retrieved in this pass.

C36. Almheiri, A., Hartman, T., Maldacena, J., Shaghoulian, E., and Tajdini, A. 2020. *Replica Wormholes and the Entropy of Hawking Radiation*. arXiv 1911.12333v2; JHEP 05, 013. Replica saddles and island rule in a controlled two-dimensional setting.

Information and technology source notes

Source notes for Chapters 4 and 5. Checked 28 October 2026. A retrieved abstract or publisher record is not represented as a full-paper review. The exact URLs below identify the material actually inspected; publication DOIs distinguish the version of record when available. These sources support bounded physical or historical claims, not the relational model as a validated theory. No source establishes a personal-survival technology or a universal biological-to-digital efficiency ratio.

I01 Hawking radiation

Hawking, S. W. 1975. Particle creation by black holes. *Communications in Mathematical Physics* 43, 199–220. https://doi.org/10.1007/BF02345020. Original paper PDF: https://projecteuclid.org/journals/communications-in-mathematical-physics/volume-43/issue-3/Particle-creation-by-black-holes/cmp/1103899181.pdf.

Access: publisher abstract and original-paper PDF text. Use: semiclassical radiation and temperature, with stationary parameters and the approximations of the calculation. It is theoretical, not a direct astronomical measurement. The lifetime displayed in this revision is a separately labeled ideal-blackbody calculation, not a fitted result from this paper.

I02 Page radiation information

Page, D. N. 1993. Information in black hole radiation. *Physical Review Letters* 71, 3743–3746. https://doi.org/10.1103/PhysRevLett.71.3743. https://arxiv.org/abs/hep-th/9306083v2. Original-paper PDF: https://harvest.aps.org/v2/journals/articles/10.1103/PhysRevLett.71.3743/fulltext.

Access: arXiv metadata/abstract and publisher full-text extract. Use: information-release expectations conditional on unitary formation and evaporation and the statistical model. A Page curve is not itself an observed radiation record or an explicit efficient decoder.

I03 Island and radiation entropy evidence

Almheiri, A., Hartman, T., Maldacena, J., Shaghoulian, E., and Tajdini, A. 2021. The entropy of Hawking radiation. *Reviews of Modern Physics* 93, 035002. https://doi.org/10.1103/RevModPhys.93.035002.

https://arxiv.org/abs/2006.06872. Accepted manuscript: https://link.aps.org/accepted/10.1103/RevModPhys.93.035002.

Access: arXiv abstract, publication metadata, and accepted-manuscript extract. Use: overview by the researchers of controlled gravitational entropy calculations consistent with unitarity. The chapter does not claim that the review proves all-realistic-black-hole decoding, final-state dynamics, or cosmological information preservation.

I04 Conditional information retrieval

Hayden, P., and Preskill, J. 2007. Black holes as mirrors: quantum information in random subsystems. *Journal of High Energy Physics* 2007(09), 120. https://doi.org/10.1088/1126-6708/2007/09/120. https://arxiv.org/abs/0708.4025. Author-hosted paper: https://preskill.caltech.edu/pubs/preskill-2007-mirror.pdf.

Access: abstract and author PDF text. Use: rapidly mixing unitary dynamics and an observer with ideal control of emitted radiation. The old-hole protocol is a counterexample to the manuscript's unconditional half-of-all-radiation statement, not an engineering proposal.

I05 Decoding complexity

Harlow, D., and Hayden, P. 2013. Quantum computation vs. firewalls. *Journal of High Energy Physics* 2013(06), 85. https://arxiv.org/abs/1301.4504. https://doi.org/10.1007/JHEP06(2013)085.

Access: original arXiv abstract and revision description. Use: complexity obstruction for specified decoding thought experiments, with genericity and computational assumptions. Does not establish that no physically possible observer could ever test unitarity or recover any information.

I06 Semantic information and interventions

Kolchinsky, A., and Wolpert, D. H. 2018. Semantic information, autonomous agency and non-equilibrium statistical physics. *Interface Focus* 8, 20180041. https://doi.org/10.1098/rsfs.2018.0041. https://arxiv.org/html/1806.08053v3. Author paper: https://artemyk.github.io/assets/pdf/papers/Kolchinsky_Wolpert_2018_Semantic%20information%2C%20autonomous%20agency%20and%20non-equilibrium%20statistical%20physics.pdf.

Access: abstract and selected HTML/PDF text on setup, viability, and intervention definitions. Use: model-specific correlation interventions and viability analysis. A physical or social application must specify variables, dynamics, horizon, and admissible interventions; a shared word does not identify quantum scrambling with this operation. No Shadow Economy mapping or relational multiplier is imported.

I07 Quantum Darwinism mechanism

Zurek, W. H. 2009. Quantum Darwinism. *Nature Physics* 5, 181–188. https://doi.org/10.1038/nphys1202. https://arxiv.org/abs/0903.5082.

Access: author abstract and publication metadata; supplemented by the experimental paper I08. Use: redundant records of selected observables in environmental fragments. Not a theorem that redundancy is required for every communication act or that the measurement problem is universally settled.

I08 Quantum Darwinism experiment

Zhu, Z., Salice, K., Touil, A., Bao, Z., Song, Z., Zhang, P., Li, H., Wang, Z., Song, C., Guo, Q., Wang, H., and Mondaini, R. 2025. Observation of quantum Darwinism and the origin of classicality with superconducting circuits. *Science Advances* 11(31), eadx6857. https://doi.org/10.1126/sciadv.adx6857. https://arxiv.org/html/2504.00781v2. Publisher metadata indexed at https://pubmed.ncbi.nlm.nih.gov/40749052/.

Access: author HTML sections on apparatus, branching structures and fragment information, figures described in text, and publication metadata. Use: engineered superconducting-qubit preparation and fragment measurements. Earlier experiments are acknowledged in its introduction; the revision does not call this the first experimental test of quantum Darwinism generally. No universal coupling-strength scaling or relational-recognition requirement is inferred.

I09 Entropy bound

Bekenstein, J. D. 1981. Universal upper bound on the entropy-to-energy ratio for bounded systems. *Physical Review D* 23, 287–298. https://doi.org/10.1103/PhysRevD.23.287. https://journals.aps.org/prd/abstract/10.1103/PhysRevD.23.287. Original-paper text: https://harvest.aps.org/v2/journals/articles/10.1103/PhysRevD.23.287/fulltext.

Access: original abstract and publisher paper extract. Use: familiar ER form and its physical-system assumptions. Modern field-theoretic distinctions are addressed through I10, not ignored. Does not justify applying a single area bound to arbitrary spatial regions, equating entropy to work, or declaring the universe finite.

I10 Encoder and decoder resource restrictions

Hayden, P., and Wang, J. 2025. What exactly does Bekenstein bound? *Quantum* 9, 1664. https://doi.org/10.22331/q-2025-03-20-1664. https://arxiv.org/abs/2309.07436v3. https://arxiv.org/html/2309.07436v3.

Access: final published-version metadata, abstract and HTML passages on channel capacities and encoder restrictions. Use: specified Unruh channel and distinct decoder-only versus encoder-plus-decoder restrictions. Zero-bit capacity is also bounded in the latter construction. The manuscript's categorical “outside the ceiling” conclusion is withdrawn.

I11 Historical Landauer paper

Landauer, R. 1961. Irreversibility and heat generation in the computing process. *IBM Journal of Research and Development* 5(3), 183–191. https://doi.org/10.1147/rd.53.0183. Original-paper copy: https://sites.pitt.edu/~jdnorton/lectures/Rotman_Summer_School_2013/thermo_computing_docs/Landauer_1961.pdf.

Access: publisher metadata/abstract and original-paper extract. Use: historical link between logical information loss and physical dissipation. Modern setup conditions are specified using I12; the original suggestion that irreversible steps are essential to all useful computation is not repeated.

I12 Precise Landauer setup

Reeb, D., and Wolf, M. M. 2014. An improved Landauer principle with finite-size corrections. *New Journal of Physics* 16, 103011. https://doi.org/10.1088/1367-2630/16/10/103011. https://arxiv.org/html/1306.4352v3. Author/institution PDF: https://mediatum.ub.tum.de/doc/1653576/1653576.pdf.

Access: HTML setup, bound and correlation sections and institutional PDF extract. Use: initially product system–thermal-reservoir state and joint unitary evolution; bounds on mean reservoir heat versus memory entropy decrease. Finite reservoirs and initial correlations alter the simplest analysis. Not a per-event biological tax.

I13 Reversible computation

Bennett, C. H. 1973. Logical reversibility of computation. *IBM Journal of Research and Development* 17, 525–532. https://doi.org/10.1147/rd.176.0525. Original-paper HTML: https://www.cs.princeton.edu/courses/archive/fall04/cos576/papers/bennett73.html.

Access: original-paper HTML, including the reversible construction. Use: reversible embedding, retention of information, and uncomputation. Separately checked Bennett's 2003 *Notes on Landauer's principle, reversible computation and Maxwell's demon*: https://arxiv.org/abs/physics/0210005, https://doi.org/10.1016/S1355-2198(03)00039-X (abstract). Logical reversibility does not certify a practical device's energy or speed.

I14 Erasure with quantum side information

del Rio, L., Åberg, J., Renner, R., Dahlsten, O., and Vedral, V. 2011. The thermodynamic meaning of negative entropy. *Nature* 474, 61–63. https://doi.org/10.1038/nature10123. https://arxiv.org/abs/1009.1630. Clarifying addendum: *Nature* 476, 476, https://www.nature.com/articles/nature10395.

Access: original author abstract and full short publisher addendum. Use: work costs with quantum side information and consumed entanglement. The addendum explicitly distinguishes such a process from a cyclic second-law violation. Heat and work are not treated as interchangeable in the chapter.

I15 Colloidal reset experiment

Bérut, A., Arakelyan, A., Petrosyan, A., Ciliberto, S., Dillenschneider, R., and Lutz, E. 2012. Experimental verification of Landauer's principle linking information and thermodynamics. *Nature* 483, 187–189. https://doi.org/10.1038/nature10872. https://www.nature.com/articles/nature10872.

Access: publisher abstract and metadata. Use: single-particle colloidal memory-reset experiment. Later platforms complement rather than invalidate or “supersede” its evidence.

I16 Nanomagnetic reset experiment

Hong, J., Lambson, B., Dhuey, S., and Bokor, J. 2016. Experimental test of Landauer's principle in single-bit operations on nanomagnetic memory bits. *Science Advances* 2, e1501492. https://doi.org/10.1126/sciadv.1501492. https://pmc.ncbi.nlm.nih.gov/articles/PMC4795654/.

Access: paper text including methods, discussion and uncertainty. Use: intrinsic dissipation in the specified reset; consistency within two standard deviations, with actuation losses excluded. The revision omits an unqualified single central value and “44 percent” summary. See the separate arithmetic check rather than treating it as a new measurement.

I17 Molecular-spin reset experiment

Gaudenzi, R., Burzurí, E., Maegawa, S., van der Zant, H. S. J., and Luis, F. 2018. Quantum Landauer erasure with a molecular nanomagnet. *Nature Physics* 14, 565–568. https://doi.org/10.1038/s41567-018-0070-7. https://www.nature.com/articles/s41567-018-0070-7. Author version: https://arxiv.org/abs/1703.04607. Correction: https://www.nature.com/articles/s41567-018-0140-x.pdf.

Access: publisher and author abstracts plus complete correction text. Use: quantum-spin memory investigation, not universal low-temperature reversibility. The correction swaps figure-legend symbols; it is recorded rather than silently ignored. Detailed numerical saturation claims are not made on abstract-only access.

I18 Many-body information thermodynamics experiment

Aimet, S., Tajik, M., Tournaire, G., Schüttelkopf, P., Sabino, J., Sotiriadis, S., Guarnieri, G., Schmiedmayer, J., and Eisert, J. 2025. Experimentally probing Landauer's principle in the quantum many-body regime. *Nature Physics* 21, 1326–1331. https://doi.org/10.1038/s41567-025-02930-9. https://www.nature.com/articles/s41567-025-02930-9. https://arxiv.org/abs/2407.21690.

Access: publisher article extracts including methods and information-thermodynamic results, and author abstract. Use: quench and reconstruction in coupled one-dimensional Bose gases; partitions, correlations and reservoir state matter. Aimet and Tajik are co-first authors. The original abbreviated “Tajik et al.” chain omitted the first author. This is not a direct observation of the framework's transducer stages.

I19 Black-hole Landauer relation

Cortês, M., and Liddle, A. R. 2024. Hawking evaporation and the Landauer Principle. https://arxiv.org/abs/2407.08777v2. https://arxiv.org/html/2407.08777v2. https://doi.org/10.48550/arXiv.2407.08777.

Access: author HTML entropy–mass derivation and scope discussion, and arXiv submission/revision metadata (11 July / 12 August 2024). An HTML body date displayed in 2026 is not substituted for that history. Use: differential Schwarzschild entropy–mass–temperature relation, with a separately discussed phenomenological extension. The authors leave the information-loss question aside. The result is **theoretical, not experimental**; prior dependency correction V501 remains intact.

I20 Cosmological entropy construction

Odintsov, S. D., Paul, T., and SenGupta, S. 2025 version. Natural validation of the second law of thermodynamics in cosmology. Originally submitted 2024; v2 dated 4 February 2025. https://arxiv.org/abs/2409.05009v2. https://arxiv.org/html/2409.05009v2.

Access: author HTML introduction and FLRW apparent-horizon setup. Use: spatially flat FLRW, apparent-horizon entropy/temperature and the authors' matter-temperature construction. Their transition result is model-specific. Not evidence for a universal reset law across all cosmic eras or for an independently measured cosmological entropy account.

I21 Everett formulation

Everett, H., III. 1957. “Relative State” formulation of quantum mechanics. *Reviews of Modern Physics* 29, 454–462. https://doi.org/10.1103/RevModPhys.29.454. https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.29.454. Original-paper scan inspected: https://quantmagic.narod.ru/Articles/Everett.pdf.

Access: publisher metadata, with publisher full text access-limited, and original-paper scan extract. Use: unitary relative-state formulation. Branch resource multiplication and a heat penalty per branch are not results of this paper. The Bell-state calculation in this volume is independent elementary algebra, not attributed to a claim about all Everettian histories.

I22 Entanglement Past Hypothesis

Al-Khalili, J., and Chen, E. K. 2024. The decoherent arrow of time and the Entanglement Past Hypothesis. *Foundations of Physics* 54, 49. https://doi.org/10.1007/s10701-024-00785-3. https://arxiv.org/abs/2405.03418. Published author copy: https://philsci-archive.pitt.edu/23719/1/Al-Khalili_Chen_FoP%202024.pdf.

Access: author abstract and published-paper extract. Use: proposed low-entanglement boundary condition and acknowledged open questions. It does not prove branchwise irreversible heat generation or establish one arrow as experimentally more fundamental.

I23 Whole-brain emulation roadmap

Sandberg, A., and Bostrom, N. 2008. *Whole brain emulation: A roadmap*. Future of Humanity Institute Technical Report 2008-3. https://ora.ox.ac.uk/objects/uuid%3Aa6880196-34c7-47a0-80f1-74d32ab98788. https://www.fhi.ox.ac.uk/reports/2008-3.pdf.

Access: institutional record and technical-report excerpts. Use: technical prerequisites and research-proposal status, not a demonstration. No current claim of achieved personal transfer is inferred from a historical roadmap; the chapter makes no forecast or exhaustive claim about all current simulation projects.

I24 Neuromorphic language-model study

Abreu, S., Shrestha, S. B., Zhu, R.-J., and Eshraghian, J. 2025. Neuromorphic principles for efficient large language models on Intel Loihi 2. ICLR SCOPE workshop; https://arxiv.org/abs/2503.18002v2; https://arxiv.org/html/2503.18002v2.

Access: v1 and latest v2 HTML, with abstract, results and relevant Appendix A.4 passages inspected. Use: preliminary component-based estimates, multi-chip implementation, and omitted embedding/unembedding stages. “ICLR 2025” is narrowed to the workshop. No end-to-end measured twofold advantage, universal neuromorphic ratio, or biological equivalence is claimed.

I25 Hala Point developer announcement

Intel. 2024. Intel builds world's largest neuromorphic system to enable more sustainable AI. 17 April 2024. https://newsroom.intel.com/artificial-intelligence/intel-builds-worlds-largest-neuromorphic-system-to-enable-more-sustainable-ai. Archived announcement with footnotes: https://download.intel.com/newsroom/archive/2025/en-us-2024-04-17-intel-builds-worlds-largest-neuromorphic-system-to-enable-more-sustainable-ai.pdf.

Access: developer announcement and benchmark footnotes. Use: historical research-system description. This is a first-party performance claim, not independent validation. Its synthetic sparse MLP characterization and earlier Loihi workload citations do not establish a general Hala Point speedup or an owl-brain-equivalent function.

I26 Sandia deployment record

Sandia National Laboratories. 2025 reporting period. Advancing neuromorphic computing at the Neural Exploration and Research Lab. https://www.sandia.gov/news/publications/hpc-annual-reports/article/advancing-neuromorphic-computing-at-the-neural-exploration-and-research-lab/. Related institutional report: https://www.sandia.gov/app/uploads/sites/81/2025/06/labnews_06-12-25.pdf.

Access: institutional report and June 2025 newsletter extract. Use: deployment of SpiNNaker2 and Loihi2; not a task-matched biology comparison. The reported eighteenfold GPU efficiency statement lacks a common-task specification adequate for this chapter, so its number is not imported. The original tenfold predecessor-efficiency claim is not verified by these retrieved records.

I27 Reversible-computing theory

Frank, M. P., and Shukla, K. 2021. Quantum foundations of classical reversible computing. *Entropy* 23, 701. https://doi.org/10.3390/e23060701. https://arxiv.org/abs/2105.00065. https://pmc.ncbi.nlm.nih.gov/articles/PMC8228632/. Institutional paper: https://www.sandia.gov/app/uploads/sites/210/2022/06/QFoCRC-OSTIv2.pdf.

Access: article theory extracts and author abstract. Use: nonequilibrium quantum description and research directions for reversible computing. Corrects the original author attribution “Frank, Ammerål, and others.” Does not establish Ice River measurements or a commercial delivery date.

I28 Origin of longevity escape velocity proposal

de Grey, A. D. N. J. 2004. Escape velocity: Why the prospect of extreme human life extension matters now. *PLOS Biology* 2(6), e187. https://doi.org/10.1371/journal.pbio.0020187. https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.0020187.

Access: publisher record and argument summary. Use: a prospective concept, not an intervention trial. No efficacy, safety, date of arrival, or ranking is taken from this essay.

I29 Human longevity trend evidence

Olshansky, S. J., Willcox, B. J., Demetrius, L., and Beltrán-Sánchez, H. 2024. Implausibility of radical life extension in humans in the twenty-first century. *Nature Aging* 4, 1635–1642. https://doi.org/10.1038/s43587-024-00702-3. https://www.nature.com/articles/s43587-024-00702-3.

Access: publisher article abstract, analysis and conclusion extracts. Use: demographic analysis under its population and historical-period definitions. It is not an absolute physical maximum on an individual's lifespan, proof against all future interventions, or a clinical recommendation.

I30 Zurek monograph metadata

Zurek, W. H. 2025. *Decoherence and Quantum Darwinism: From Quantum Foundations to Classical Reality*. Cambridge University Press. https://doi.org/10.1017/9781009552868. https://www.cambridge.org/core/books/decoherence-and-quantum-darwinism/E851B8F658044E4BF549AAEEB7B47B37. https://assets.cambridge.org/97810095/52905/frontmatter/9781009552905_frontmatter.pdf.

Access: publisher description, metadata and frontmatter only; full book not read. Original source mention is retained in this disposition record. Scientific claims in the revised body rely on I07–I08 instead of calling an access-limited book “definitive.”

I31 Analogue Hawking experiment

Muñoz de Nova, J. R., Golubkov, K., Kolobov, V. I., and Steinhauer, J. 2019. Observation of thermal Hawking radiation and its temperature in an analogue black hole. *Nature* 569, 688–691. https://doi.org/10.1038/s41586-019-1241-0. https://www.nature.com/articles/s41586-019-1241-0. https://arxiv.org/abs/1809.00913.

Access: publisher abstract and author abstract. Use: correlations and temperature in an analogue platform. Does not constitute observation of astrophysical evaporation, a Page curve of an actual black hole, or a test of Cortês–Liddle's calculation.

I32 Stationary black-hole mechanics

Bardeen, J. M., Carter, B., and Hawking, S. W. 1973. The four laws of black hole mechanics. *Communications in Mathematical Physics* 31, 161–170. https://doi.org/10.1007/BF01645742. https://projecteuclid.org/journals/communications-in-mathematical-physics/volume-31/issue-2/The-four-laws-of-black-hole-mechanics/cmp/1103858973.pdf.

Access: original paper extract. Use: stationary axisymmetric black-hole mechanics, including angular-momentum terms. The Kerr entropy equation is explicitly reconstructed in I-CALC-02 with fixed mass and zero charge. Schwarzschild dE = T dS is not generalized by silently dropping rotational work.

I33 Stochastic thermodynamic scope

Seifert, U. 2012. Stochastic thermodynamics, fluctuation theorems and molecular machines. *Reports on Progress in Physics* 75, 126001. https://doi.org/10.1088/0034-4885/75/12/126001. https://arxiv.org/abs/1205.4176. Author-paper copy: https://terpconnect.umd.edu/~cjarzyns/CHEM-CHPH-PHYS_703_Spr_20/resources/Rep%20Prog%20Phys%202012%20Seifert.pdf.

Access: author abstract and paper text extract. Use: heat-bath-coupled, specified stochastic ensembles and fluctuating trajectories. Supports separating macroscopic or average production statements from every single-event claim. Does not make aging one scalar entropy variable.

I34 Cosmological apparent-horizon proposal

Trivedi, O. 2024. Landauer's principle and information at the cosmological horizon. https://arxiv.org/abs/2407.15231v3. https://arxiv.org/html/2407.15231v3. Latest inspected revision 25 December 2024.

Access: metadata, author abstract, HTML introduction and model setup. Use: a specific apparent-horizon thermodynamic construction and its claimed tension. “Cosmological information paradox” is the author's terminology, not evidence for a generally established violation of Landauer's principle. The revision does not adopt the paper's broad statement that every computation necessarily dissipates energy.

Cosmology source access and unresolved numerical discrepancy

“Targeted full-text” below means the specified sections of an accessible primary text were examined; it does not mean every derivation was independently reproduced. Metadata/abstract-only entries support only the narrow qualitative use stated. No claim of exhaustive literature coverage or human peer review is made.

C01. Access scope: Primary arXiv v3 HTML abstract, §I.1–I.2, Table 1, component definitions, horizon/interior distinction; abstract supplies Table 2 central totals. Conditions and limits: Historical flat cosmology and its chosen volumes; no current-census certification.

C02. Access scope: v2 abstract/metadata; HTML §§1–3, 7–9 and Table 3; PDF parsed equations on printed pp24–25 and Table 3 on p37; independent reviewer visually checked those three pages. Conditions and limits: See discrepancy below; no numerical repair invented.

C03. Access scope: v1 primary abstract and repository status. Conditions and limits: Submitted preprint; specific population synthesis, mass range and redshift result, not a verified cosmic history.

C04. Access scope: Publisher abstract and accessible original-paper search extract. Conditions and limits: Complete bounded system and gravitational assumptions; not universal cosmological application.

C05. Access scope: Bekenstein and Hawking publisher abstracts/metadata; Schwarzschild equations also directly checked in C28 §II. Conditions and limits: No primary full-paper derivation re-audit; semiclassical law rather than experimental evaporation.

C06. Access scope: Primary publisher-hosted full-text opening and abstract via indexed record. Conditions and limits: Positive cosmological constant setting; equations cross-checked with C01/C02 and direct algebra.

C07. Access scope: Primary arXiv abstract. Conditions and limits: Original conjecture; null light-sheet qualifications retained, not claimed unrestricted proof.

C08. Access scope: v5 primary abstract, accessible HTML construction and scope, static-patch result. Conditions and limits: Observer-dressed semiclassical construction; additive entropy normalization; no arbitrary-cosmology extension.

C09. Access scope: v2 primary HTML abstract, introduction and stated derivation assumptions. Conditions and limits: Equipartition regime and sign-dependent deformation; no universal Planck-scale tightening.

C10. Access scope: v16 primary abstract and metadata. Conditions and limits: A proposed local thermodynamics; dimension claim confined to that construction.

C11. Access scope: Primary abstract and metadata, with continuity to earlier verified volume discussion. Conditions and limits: Stochastic microscopically reversible process and heat-bath/work setup, not arbitrary cosmic free energy.

C12. Access scope: Primary experiment abstract and publisher identity. Conditions and limits: Neutral B-meson result suffices to refute all-laws T symmetry; no claim that it explains thermodynamic arrow.

C13. Access scope: v1 primary abstract and metadata. Conditions and limits: Explicitly a proposed cosmology, not source of a settled initial-condition theorem.

C14. Access scope: v1 primary HTML abstract, simple system–environment model and entropy distinctions. Conditions and limits: Subsystem partition and proposal status retained; closed-system unitary entropy distinguished.

C15. Access scope: v1 primary abstract; HTML §§2–3 available and initial-projector statement checked against author manuscript extract. Conditions and limits: The cited specific account is a 2022 preprint, not the original's conflated 2021/2024 award description.

C16. Access scope: Primary abstract and bibliographic metadata. Conditions and limits: Retains gravity-in-entropy versus entropy-of-gravity distinction only; no field entropy formula adopted.

C17. Access scope: v1 primary HTML abstract and introduction. Conditions and limits: Standard Model with physical Higgs mass; crossover, not claim of grand unification.

C18. Access scope: Primary arXiv abstract/metadata and baseline parameters. Conditions and limits: ΛCDM present energy-density fractions; approximate rounded fractions only.

C19. Access scope: Original publisher abstract and primary paper first-page extract. Conditions and limits: Early collapse model, not evidence that PBHs exist.

C20. Access scope: v3 primary metadata and abstract result. Conditions and limits: Combination-specific 2024 significance range; no standalone DESI discovery claim.

C21. Access scope: v3 primary HTML abstract, §VII.1–VII.3, Table 6 and conclusions. Conditions and limits: CMB and SNe choices explicit; no significance pooling.

C22. Access scope: v3 primary metadata, abstract, §VI.4.1, Table 4 and discussion; v1 initially inspected but superseded for citation. Conditions and limits: Submitted 29 July 2026; announcement 30 July; v3 4 August. Current-date targeted update, not prediction of later releases.

C23. Access scope: Primary abstract and metadata; standard FLRW null-geodesic formulas independently checked in the calculation record. Conditions and limits: Definitions and analytic examples do not require adopting the paper's historical parameter values.

C24. Access scope: Primary abstract and metadata. Conditions and limits: Conditional constant/sustained phantom model; no assertion all $w < -1$ histories rip.

C25. Access scope: Primary abstract, publisher identity and original-paper indexed extract. Conditions and limits: Used only to identify conditional far-future inquiry; no numerical date adopted.

C26, C27, C36. Access scope: Primary abstracts and version metadata. Conditions and limits: Their explicit JT/CFT or AdS/CFT settings preserved; no general experimental claim.

C28. Access scope: v2 primary full HTML §II equations 1–6, environment discussion and abstract. Conditions and limits: $dE = T_H\, dS_{BH}$ identity and small entropy decrement; not complete-state information destruction.

C29. Access scope: v3 primary HTML abstract, introduction and identified apparent-horizon setup. Conditions and limits: Paper's interpretation labeled model-specific; not endorsed as demonstrated violation.

C30. Access scope: v2 primary HTML abstract, setup, thermal-equilibrium and entropy-balance discussion. Conditions and limits: Apparent horizon, matter/horizon temperature prescriptions; no universal conservation result.

C31, C32. Access scope: Exact primary identities and interpretation from preserved corrected Volume 1 references and their source review. Conditions and limits: This pass did not re-retrieve those full papers; C33 freshly checks scoped erasure statement.

C33. Access scope: v3 primary abstract and HTML introduction/setup outline. Conditions and limits: Reservoir/correlation scope and reversible ideal limit; no positive total-production floor.

C34. Access scope: Primary publisher indexed abstract/metadata and author's publication list; direct publisher page returned 403. Conditions and limits: Only qualitative identification of coherent-field axion production retained; no abundance/parameter result.

C35. Access scope: Author-uploaded primary-paper abstract indexed in search and exact DOI metadata; DOI route failed and direct publisher page returned 403. Conditions and limits: Only qualitative thermal relic mechanism retained; no numeric formula or calculation attributed to unavailable full text.

The primary URLs appear in the C reference list above. Failed direct access was not described as successful full-text retrieval. Several arXiv HTML renderings display “August 24, 2026” within old manuscripts; version metadata, rather than that generated body date, controls the citation. This specifically affects C14, C17 and C28 in the inspected rendering.

The census discrepancy that remains open

C02's PDF main text gives central SMBH entropy 8.56×10^{101} k_B for its stated 10^7–$10^{9.7}$ solar-mass range (Eq7.1), and stellar-black-hole entropy 5.35×10^{96} k_B (Eq7.10). Its Table 3 instead lists logarithmic values 103.25 and 101.50. No reconciliation or explicit alternative-volume assignment was identified in this review. The ranges may matter; we do not infer the authors' intended corrected aggregate.

The numerical disagreement was also checked against the primary PDF pages, not only the HTML extraction. This volume therefore uses C02 qualitatively and does not choose either set as the corrected universe total. Its Table 3 historical-comparator entries must not be substituted for C01's own table.

Information calculation notes

Re-set from the second edition's original equation markup, with minor copyedits for clarity; no figure or conclusion was changed, and the arithmetic was rechecked for this edition.

These checks reproduce numerical arithmetic and elementary identities. They do not validate an empirical input merely because it appears in a formula. Rounded values in the chapters are intentionally less precise. The constants used are $k_B = 1.380649 \times 10^{-23}$ J/K, $h = 6.62607015 \times 10^{-34}$ J s, $\hbar = h/(2\pi)$, $c = 299792458$ m/s, $G = 6.67430 \times 10^{-11}$ $m^3/(kg\ s^2)$, $M_\odot = 1.98847 \times 10^{30}$ kg and one Julian year = 31557600 s. The SI defining values k_B, h and c are exact; G and the adopted solar mass are rounded inputs.

I-CALC-01 Schwarzschild scales and the lifetime correction

Assume an isolated, neutral, nonrotating Schwarzschild black hole. The temperature is $T_H = \hbar c^3/(8\pi G M k_B)$, the radius $r_s = 2GM/c^2$ and the entropy $S_{BH}/k_B = 4\pi GM^2/(\hbar c)$. The simple blackbody approximation takes area $A = 4\pi r_s^2$ and power $P = \sigma A T_H^4$, with $\sigma = \pi^2 k_B^4/(60\hbar^3 c^2)$. It gives $P = \hbar c^6/(15360\pi G^2 M^2)$. Integrating $c^2\, dM/dt = -P$ to zero mass yields $\tau = 5120\pi G^2 M^3/(\hbar c^4)$.

This is an explicitly idealized pedagogical estimate. It omits greybody transmission, the temperature-dependent spectrum of available particle species, angular momentum, charge, accretion and surrounding radiation. Extrapolation of the semiclassical approximation to the last stage is not a measurement or a complete quantum-gravity treatment.

Dimensional checks: $\hbar c^3/(GMk_B)$ has units K; $G^2M^3/(\hbar c^4)$ has units s; $GM^2/(\hbar c)$ is dimensionless. With the recorded approximate solar mass, the solar temperature is about 6.17×10^{-8} K, τ about 2.10×10^{67} years, and S_{BH}/k_B about 1.05×10^{77}. At 10^9 solar masses, temperature is lower by 10^9, lifetime longer by 10^{27},

and entropy larger by 10^{18}: τ about 2.10×10^{94} years and S_{BH}/k_B about 1.05×10^{95}. The original 10^{97}-year claim is incompatible with the original 10^{67}-year normalization and M^3 scaling.

For comparison with the Cortês–Liddle relation, differentiate rather than divide totals: $dS_{BH}/dM = 8\pi k_B GM/(\hbar c)$, so $T_H\, dS_{BH} = c^2\, dM = dE$. A decrease of black-hole entropy with magnitude $k_B \ln 2$ corresponds, differentially, to emitted energy $k_B T_H \ln 2$. This is not the claim that each emitted particle is one bit, that radiation entropy equals the hole's entropy decrease, or that the complete evaporation process is thermodynamically reversible. T_H varies during evaporation. For Kerr, the first law includes rotational work and this Schwarzschild reduction cannot simply be copied unchanged. [I01, I19, I32]

I-CALC-02 Bekenstein and Kerr units and limits

For $S \le 2\pi k_B ER/(\hbar c)$, ER and ħc both have units J m. The right side has units J/K. Dividing by $k_B \ln 2$ gives a dimensionless number of entropy bits, not a quantity of work in joules.

For uncharged Kerr, define $a = J/(Mc)$, $\chi = ac^2/(GM) = Jc/(GM^2)$, and $r_+ = (GM/c^2)[1 + \sqrt{(1 - \chi^2)}]$. The horizon area $A = 4\pi(r_+^2 + a^2) = 8\pi G^2M^2[1 + \sqrt{(1 - \chi^2)}]/c^4$. Substitution into $S = k_BA/(4\ell_P^2)$, with $\ell_P^2 = G\hbar/c^3$, gives $S_{Kerr} = 2\pi k_B GM^2[1 + \sqrt{(1 - \chi^2)}]/(\hbar c)$. Thus at fixed M and $|\chi| \le 1$:

$$S_{Kerr} / S_{Schwarzschild} = [1 + \sqrt{(1 - \chi^2)}] / 2$$

which lies between 1/2 and 1. Finite entropy at fixed finite M is established for this family; no statement about the universe's total volume or entropy follows. At fixed M, more spin means smaller area, so inserting a Schwarzschild formula for a spinning hole overestimates that horizon entropy. This conditional family comparison is not a general bound for any arbitrary finite region. [I09, I32]

I-CALC-03 Reset reference and heat versus production

$k_BT \ln 2$ at 300 K equals approximately 2.87098×10^{-21} J; at 310 K it is 2.96668×10^{-21} J. k_B has units J/K, T has K and ln 2 is dimensionless. Mean heat is the relevant quantity in the familiar statistical reset statement. The limiting ideal reset in the text uses equal intrastate entropies, unchanged endpoint energetics, an unbiased initial bit, an initially uncorrelated thermal reservoir, and no correlated side information used.

If one assumes the original's 4.2×10^{-21} J and 300 K, the ratio is approximately 1.463, or 46.3 percent above the reference, not 44 percent with these stated inputs. This arithmetic does not adjudicate an experimental central value or substitute for Hong's uncertainty and actuation boundary. The body therefore uses the paper's qualified consistency result and omits a spuriously exact percentage. [I16]

In an ideal isothermal reversible reset, the memory's thermodynamic entropy change is $-k_B \ln 2$ and the bath's entropy change is $+k_B \ln 2$. Their sum tends to zero. A positive heat transfer is therefore not by itself positive total entropy production. Exact saturation and perfectly pure reset are limiting idealizations, particularly for a finite-temperature finite reservoir. [I12]

I-CALC-04 Reversible change in entanglement

Start with $|00\rangle$. Apply a Hadamard gate to the first qubit and a controlled-NOT to the second. The result is $|\Phi^+\rangle = (|00\rangle + |11\rangle)/\sqrt{2}$. Both joint density operators have spectrum (1, 0, 0, 0), so both have zero von

Neumann entropy. Afterward each reduced density matrix is the identity divided by 2 and has entropy k_B ln 2. Applying the inverse two-gate sequence returns the original state.

This algebra is a counterexample to identifying subsystem entanglement increase with an unavoidable global entropy increase. It makes no claim that a macroscopic measurement can practically be reversed at no cost or that laboratory gates are dissipationless.

I-CALC-05 Original neuromorphic arithmetic

1 pJ = 10^{-12} J and 1 fJ = 10^{-15} J. The minimum ratio implied by the supplied ranges is $(20 \times 10^{-12})/(10 \times 10^{-15}) = 2{,}000$. The maximum is $(50 \times 10^{-12})/(1 \times 10^{-15}) = 50{,}000$. The manuscript's 5–50 comparison is numerically wrong. Neither endpoint establishes a common event, complete energy accounting or comparable performance. No repaired biological advantage is derived.

The separate ratios $10^9/10^6 = 1{,}000$ and $10^7/10^6 = 10$ are arithmetically correct but scientifically unsupported as universal substrate constants. Arithmetic validity cannot repair those premises, so the proposed ranking and convergence projection remain withdrawn.

I-CALC-06 Reversible embedding of an output filter

For an n-bit input x and an m-bit function value f(x), define $F(x, y) = (x, y \oplus f(x))$, where y is m bits and $\oplus$ is bitwise exclusive OR. Then $F(F(x, y)) = (x, y \oplus f(x) \oplus f(x)) = (x, y)$, so F is its own inverse. With y initially zero, the output register contains f(x), while x remains available. For the two-input-bit AND example with a one-bit auxiliary register, direct enumeration of all eight input states confirms the inverse relation.

This construction establishes logical reversibility of an embedding, not zero total physical cost. Initialization, storage, speed, control, readout, reliability, uncomputation and reuse must be included in a physical implementation. It defeats the inference from “output filtering” alone to mandatory erasure of the full input at each framework stage. [I13]