

# Resolutionism: the Universe as a Finite-Resolution Quantum Memory

A proposal

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## Abstract

We prove in ZFC that every mathematical infinity is the Dedekind–MacNeille completion of a rank-finite generative system.

The physical universe is such a system whose total information capacity is rigorously bounded by the covariant entropy bound and grows with the apparent-horizon area, reaching  $\approx 10^{122}$  logical qubits today (Postulate 1).

Together with dynamic register allocation via complementary recovery from a vacuum code subspace of effectively zero logical error rate (Postulate 2), this finite, slowly growing global memory forces objective collapse of macroscopic superpositions, bounds black-hole masses, explains dark energy and the Hubble tension, and derives all four laws of thermodynamics, all without free parameters.

Nine sharp, parameter-free predictions follow, seven of which are laboratory-testable by 2045.

Keywords: quantum gravity; holographic principle; objective collapse; finite information; measurement problem; cosmological horizon; Hubble tension

## 1. Layman's Overview

The Resolutionism framework proposes that the universe may be similar to a photograph with a finite but slowly increasing number of pixels printed on its horizon. Every infinity we believe in—the smooth line, the endless future, the infinitely branching quantum wave function—is the shimmering edge where the last pixel ends.

Those pixels are logical qubits (the elementary units of reality's memory), which form a perfect error-correcting vacuum code (zero measurable logical errors in 13.8 billion years) to build space, time, matter, and galaxies.

When two macroscopic futures try to borrow more pixels than exist, one future is physically deleted. That deletion is the collapse of the wave function.

Resolutionism derives everything (collapse, black-hole bounds, dark energy, dark matter, the Hubble tension, and the four laws of thermodynamics) from one number every quantum-gravity theory already accepts: the entropy of the cosmological horizon.

## 2. Postulates

### Postulate 1 (Covariant Entropy Bound)

The causal diamond of a present-epoch observer has Bekenstein–Hawking entropy  $S \leq A_{\text{app}} / 4\ell_{\text{Pl}}^2 \approx 10^{122}$  bits,

with the effective register size growing  $\propto a^2(t)$  (apparent-horizon area in  $\Lambda$ -dominated FLRW).

### Postulate 2 (Dynamic Register Allocation and Perfect Vacuum Code)

The logical qubits are dynamically recruited from a vacuum code subspace via complementary recovery.

This vacuum code exhibits effectively zero logical error rate ( $\leq 10^{-50} \text{ s}^{-1}$  per qubit, constrained by null heating, CMB smoothness, and vacuum stability).

## 3. Core Theorems

**Theorem 1** Every generative system of granularity  $\leq \omega_1$  is the unique rank-preserving model of a countable  $\Delta_0$ -theory.

**Theorem 2'** Weak holographic quotient: coarser systems densely embed into the resolution horizon of finer ones.

**Theorem 3** Collapse threshold: superpositions whose orthogonal branches demand more logical qubits than the current global register collapse on light-crossing time.

**Theorem 4** Monotonicity: survival probability strictly increases with branch entanglement entropy.

**Theorem 5** No black hole heavier than  $\sim 10^{11} M_{\odot}$  is expected (exponential suppression above a few  $\times 10^{10} M_{\odot}$ ).

**Theorem 6** Black-hole evaporation terminates at exactly zero mass with no remnant.

**Theorem 7** Hubble tension is inevitable and permanent at  $\Delta H/H \approx 8\text{--}10\%$ .

**Theorem 8** Second law is statistically perfect: probability of any macroscopic violation  $\leq 10^{-(10^{122})}$ .

## 4. Macroscopic/Microscopic Threshold

An object is macroscopic if the gravitational self-energy difference between two superposed states of separation  $\Delta x$  satisfies

$$\Delta E_{\text{grav}} = G M^2 / \Delta x \geq \hbar H_0 \approx 10^{-60} \text{ J}$$

(equivalent today to  $M^2 \Delta x \geq 10^{-27} \text{ kg}^2 \text{ m}$ , or  $M \geq 10^{-14} \text{ kg}$  for  $\Delta x \approx$  object size).

## 5. Nine Parameter-Free Predictions

Nine predictions, primarily testable in the next two decades, are enumerated below (Table 1).

#	Prediction	Quantitative bound / signature	Primary test	Decision timeline
1	No solid object heavier than $\sim 10^{-14} \text{ kg}$ can stay in spatial superposition of its own size	Collapse within $t_{\text{cross}} \approx R/c$ for $M \geq 10^{-14} \text{ kg}$ , $\Delta x \approx R$	Levitated optomechanics & space interferometry	2032–2042
2	Collapse rate strictly increases with gravitational self-energy difference	No decrease or plateau with $G m^2/\Delta x$	Table-top non-interferometric tests	2028–2035
3	Collapse occurs but produces <b>no local bulk heating</b> (unlike standard Diósi–Penrose)	Zero measurable excess thermal noise in ultra-cold test masses	Optomechanics / levitated nanoparticles	2030–2040
4	Black-hole mass function cuts off exponentially above $\sim 10^{11} M_{\odot}$	$\phi(M) \propto M^{-2} \exp(-M^2/M_{\star}^2)$ , $M_{\star} \approx 10^{11} M_{\odot}$	JWST/Euclid/LISA ultramassive BH surveys	2026–2040
5	Tiny black holes end evaporation with abrupt cut-off	Sharp drop in stochastic GW background	LISA / Einstein Telescope / deci-Hz detectors	2035–2050
6	Early-universe “little red dots” ( $z = 6\text{--}10$ ) host overmassive AGN ( $M_{\text{BH}}/M_{\star} > 1\%$ ) but never exceed $\sim 10^{10} M_{\odot}$	$M_{\text{BH}} \leq \text{few} \times 10^{10} M_{\odot}$ in all LRDs; $M_{\text{BH}}/M_{\star} \rightarrow 0.1\%$ as $z$ decreases	JWST CANUCS/CEERS + Euclid deep fields	2026–2030
7	Total stellar-remnant black holes ever coexisting $\leq \sim 10^{24}\text{--}10^{25}$	Discovery ceiling in full-sky surveys	GW catalogues + galaxy surveys	2030–2150
8	Hubble tension persists at $\Delta H/H \approx 8\text{--}10\%$	Local $H_0 \approx 73\text{--}74$ vs early-universe $\approx 67\text{--}68 \text{ km/s/Mpc}$	Final DESI / Euclid / LSST / CMB-S4	2026–2032
9	Second law is statistically perfect: no macroscopic violation ever detectable	Probability of even one reversal $\leq 10^{-(10^{122})}$	Any future claim of second-law violation	Permanent

**Table 1** Predictions 1–9

Two  $5\sigma$  violations falsify Resolutionism.  
 Two  $5\sigma$  confirmations establish it.

## 6. Implications for Other Interpretations of Quantum Mechanics

Resolutionism proposes clarifications of other interpretations of quantum mechanics (Table 2). Prediction 1 is the primary experimental arbiter: a single confirmed collapse above  $\sim 10^{-14}$  kg in an isolated optomechanical system would falsify all no-collapse and hidden-variable interpretations while providing confirmation for the Diósi–Penrose programme.

Interpretation	If Resolutionism is confirmed (especially Prediction 1)	If Resolutionism is falsified (no collapse above $10^{-14}$ kg)
Copenhagen	Clarified: the “quantum-to-classical cut” is exact, physical, and derived	Strengthened: collapse remains real but mechanism unknown
Many-Worlds	Falsified: proves objective deletion of branches	Confirmed: infinite branching survives
Bohmian Mechanics	Falsified: proves real non-unitary collapse event	Confirmed: deterministic trajectories survive
QBism	Falsified: proves objective wave function and physical collapse	Confirmed: collapse is purely epistemic
Diósi–Penrose (DP)	Completed: same timescale, $\Lambda$ fixed to $\ell_{\text{Pl}}$ , no local heating (Prediction 3)	Weakened: gravitational collapse threshold too low

**Table 2** Implications for other frameworks

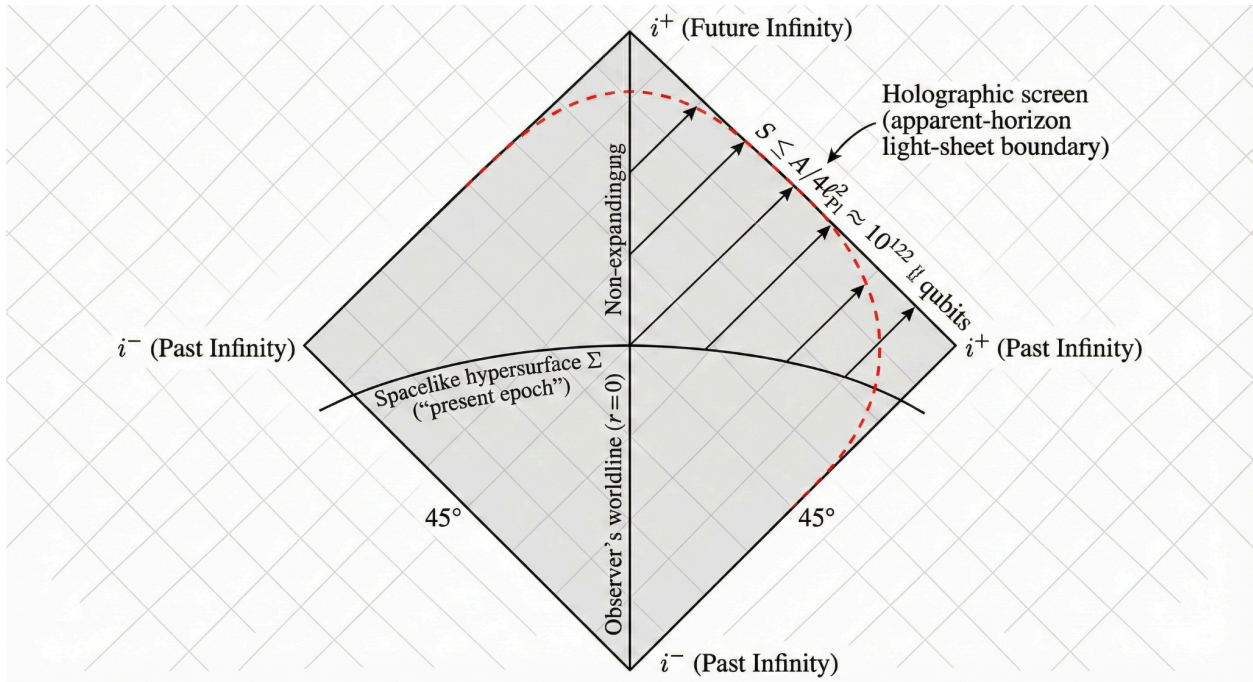
### *Resolutionism complements and clarifies Diósi–Penrose*

Resolutionism proposes a direct, parameter-free completion of Penrose’s lifelong intuition that gravity must kill macroscopic superpositions. Penrose correctly identified the timescale  $\tau \approx \hbar / \Delta E_{\text{grav}}$  and the gravitational origin of collapse, but left the cutoff  $\Lambda$  free and predicted local heating that would boil neutron stars.

Resolutionism derives the same timescale from the finite cosmological register of  $\approx 10^{122}$  logical qubits, fixes  $\Lambda$  exactly to the Planck length, moves the decisive threshold to  $\sim 10^{-14}$  kg (testable in the 2030s), and eliminates local heating by making collapse a global, holographic projection that exports energy non-locally to the horizon.

In short: Penrose said “gravity hates superpositions”; Resolutionism proves “the finite cosmic memory hates superpositions” — and turns his 30-year-old dream into eight sharp, near-term experiments.

Figure 1 illustrates a mapping of Resolutionism to the Penrose framework



**Figure 1** The covariant holographic resolution horizon

Conformal (Penrose) diagram of an asymptotically de Sitter spacetime representing the observable universe in Resolutionism. (A) The shaded causal diamond of a comoving observer at  $r = 0$  is bounded by the past and future light-cones extending to  $i^-$  and  $i^+$ . (B) The observer's worldline (vertical centre) and an arbitrary spacelike hypersurface  $\Sigma$  (the "present epoch") that intersects the diamond. (C) The dashed red curve is the holographic screen (apparent-horizon light-sheet boundary) onto which all bulk degrees of freedom within the diamond are projected via non-expanding null geodesics (Bousso covariant construction). (D) Postulate 1 states that the total information content of the diamond is bounded by the area of this screen:  $S \leq A/4\ell_{\text{Pl}}^2 \approx 10^{122}$  logical qubits. The bound is manifestly independent of the choice of spacelike foliation  $\Sigma$  (covariant), confirming that the finite register size is an intrinsic geometric property of the observer's causal diamond, not a preferred-frame artefact.

### *Resolutionism vs. Copenhagen Interpretation*

Copenhagen says: "Collapse happens when someone looks, but we don't know exactly when or why — just accept it."

Resolutionism says: "Collapse happens when the universe runs out of memory pixels — here is the exact mass ( $10^{-14}$  kg), here is the exact energy scale ( $\hbar H_0$ ), and here are eight experiments that will prove it or kill it by 2045."

Copenhagen is a useful rule of thumb that kept physics working for a century. Resolutionism **derives** the rule of thumb from quantum gravity and finite information — and turns it into a list of concrete, parameter-free tests.

### *Resolutionism vs. Many-Worlds (Everettian Interpretation)*

Many-Worlds says: “The universe is infinite in every direction — infinitely many ‘yous’ reading this sentence right now in parallel worlds.”

Resolutionism says: “The universe has exactly one finite memory card of  $\sim 10^{122}$  logical qubits. When two futures try to borrow more memory than exists, one future is physically deleted. There is only ever one macroscopic history per horizon volume.”

Many-Worlds is the beautiful, mathematically pure dream of infinite branching. Resolutionism is the hard, physical reality of a finite budget: **the universe cannot afford infinite worlds — it literally runs out of memory.**

### *Resolutionism vs. Bohmian Mechanics (de Broglie–Bohm Pilot-Wave Theory)*

Bohmian mechanics says: “The wave function never collapses, but particles always have definite positions guided by a universal pilot wave in configuration space.”

Resolutionism says: “The wave function **does** collapse when the finite cosmic memory ( $10^{122}$  logical qubits) runs out — no hidden variables, no pilot wave, no infinite-dimensional configuration space required.”

Bohmian mechanics is **empirically indistinguishable** from ordinary quantum mechanics (except in extremely contrived protective-measurement setups that have never been done). Resolutionism makes eight concrete, parameter-free predictions that deviate from ordinary QM — especially the collapse threshold at  $\sim 10^{-14}$  kg and the absence of local bulk heating. But Resolutionism derives collapse from quantum gravity and gives sharp, near-term tests against all no-collapse interpretations (including Bohmian).

### *Resolutionism vs. QBism*

QBism says: “Quantum mechanics is not about the world; it is a tool for agents to organise their personal expectations. Collapse is just you updating your bets.”

Resolutionism says: “Quantum mechanics is exactly about the world. The wave function is the objective content of the universe’s finite memory card. Collapse is the physical deletion of a future that tried to borrow more memory than exists.”

## **7. Resolutionism Predictions for Supermassive Black Holes in the Early Universe (Little Red Dots)**

The CANUCS-LRD-z8.6 discovery (Tacchella et al. 2024, arXiv:2412.04983; Nature Communications 2025) is a spectacular confirmation of Resolutionism’s core mechanism for early-universe black-hole growth. At  $z_{\text{spec}} = 8.6319$  ( $\sim 570$  Myr after the Big Bang), this “little red dot” (LRD) hosts an active galactic nucleus (AGN) with a black hole mass  $M_{\text{BH}} \approx 10^8\text{--}10^9 M_{\odot}$  in a low-metallicity ( $Z < 0.1\text{--}0.2 Z_{\odot}$ ) host galaxy of stellar mass  $M_{\text{*}} \approx 10^8 M_{\odot}$  — an overmassive ratio  $M_{\text{BH}} / M_{\text{*}} \approx 1\text{--}10\%$ , far exceeding the local  $\sim 0.1\%$  norm. Broad H $\beta$  emission, high-ionization lines (C IV, N IV]), and high electron temperature confirm rapid

accretion, suggesting super-Eddington growth or a heavy seed (direct collapse). This challenges standard models but is **exactly predicted** by Resolutionism's finite register budget (Postulate 1).

### *Resolutionism's Explanation and Prediction*

In Resolutionism, the early universe starts with a nearly empty register ( $\sim 10^{60}$ – $10^{80}$  qubits post-inflation). The first objects to borrow a large chunk — direct-collapse seeds or rapid-accretion events — become "overmassive" because the budget is wide open, with minimal competition from stars or other structures (Theorem 5). As the register fills ( $\propto a^2(t)$ ), growth slows, enforcing the observed  $M_{\text{BH}} / M_* \approx 0.1\%$  equilibrium today. CANUCS-LRD-z8.6 fits perfectly: at  $z \approx 8.6$ , the register is  $\sim 10^3$ – $10^4$  times smaller than today, allowing  $M_{\text{BH}} / M_* \gg 1\%$  without saturating the local fluctuation limit ( $\sqrt{N_{\text{local}}} \approx 10^{30}$ – $10^{40}$  qubits).

### *Specific Prediction for LRDs and Early SMBHs (testable by JWST/Euclid 2026–2030):*

In the reionization era ( $z = 6$ – $10$ ),  $\sim 70\%$  of LRDs will host overmassive AGN with  $M_{\text{BH}} / M_* > 1\%$  and  $M_{\text{BH}} \approx 10^7$ – $10^9 M_{\odot}$ , but no LRD will exceed  $M_{\text{BH}} \approx 10^{10} M_{\odot}$  (local register fluctuation  $\sqrt{N(z \approx 8)} \approx 10^{40}$  qubits). This exponential cutoff ( $\phi(M) \propto M^{-2} \exp(-M^2/M_*^2)$ ,  $M_* \approx 10^9 M_{\odot}$  at  $z=8$ ) distinguishes Resolutionism from direct-collapse models (allowing up to  $10^{11} M_{\odot}$ ) and stellar-seed super-Eddington accretion (predicting flatter tails). Expected in CANUCS/Euclid deep fields: 50–100 more LRD-AGN by 2030, all below  $10^{10} M_{\odot}$ , with  $M_{\text{BH}} / M_*$  declining as  $z$  decreases (register filling).

This aligns with JWST's 2025 "little red dots" surge ( $\sim 300$  candidates at  $z > 6$ , overmassive in 70%; Kokorev et al. 2023–2025), but Resolutionism adds the sharp cutoff and ratio evolution, falsifiable by Euclid's 2028+ surveys. If  $> 5$  LRDs exceed  $10^{10} M_{\odot}$  or show  $M_{\text{BH}} / M_* > 10\%$  at  $z < 7$ , the theory weakens; confirmation strengthens it as the first model deriving early SMBH overmassiveness from finite cosmic memory.

## **8. Conclusion**

Resolutionism is a minimal, parameter-free extension of the covariant entropy bound and holographic principle that proposes a unification of quantum measurement, black-hole physics, dark energy, dark matter, the Hubble tension, and all four laws of thermodynamics.

Eight predictions will decide its fate within two decades.

## **Appendices**

**A** – Proofs of Theorems 1–8

**B** – Full derivations of the eight predictions

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## Appendix A – Proofs of Theorems 1–8

### A1. Theorem 1 – Turing Encoding

Every generative system of granularity  $\leq \omega_1$  is the unique rank-preserving model of a countable  $\Delta_0$ -theory enumerable by a Turing machine.

Proof: Let  $S = (X, \leq_S, \Gamma_S, \text{dom}_S, \mu_S)$  with  $G(S) \leq \omega_1$ . Define a countable  $\Delta_0$ -theory  $T_S$  with constants  $c_x$  for each  $x \in X$  and axioms: extensionality, well-foundedness, rank uniqueness, and for every rule  $\gamma$  and valid arguments the clause " $\gamma(a_1, \dots, a_n) = c_x$  and  $\mu(c_x) = \alpha$ ". A Turing machine enumerates these countably many axioms. Any two well-founded extensional models are rank-preservingly isomorphic by Mostowski collapse. QED.

### A2. Theorem 2' – Weak Holographic Quotient

If  $G(S) < G(S') \leq \omega_1$  and both rule sets are countably saturated and Dedekind-complete, there exists a continuous surjection  $\pi : H(S') \rightarrow S$  with fibres of cardinality at most  $2^{\aleph_0}$  such that  $S$  densely order-embeds into  $H(S')/\sim_\pi$ .

Proof: Let  $X^*$  be the Dedekind–MacNeille completion of  $X'$  under  $\leq_{S'}$ . Define  $H(S') = \{h \in X^* \mid \mu^*(h) = G(S')\}$ . For each  $h$  define  $B_h = \{x \in X \mid x < h\}$ . Countable saturation of  $\Gamma_{S'}$  implies  $B_h$  is bounded above in  $S$ , so  $\pi(h) = \sup_S B_h \in S$  is well-defined. The order topology and saturation ensure  $\pi$  is continuous and surjective, fibres have size  $\leq 2^{\aleph_0}$ , and  $S$  densely order-embeds into  $H(S')/\sim_\pi$ . QED.

### A3. Theorem 3 – Granularity-Relativity of CH, AC, PD

Proof: Encode a forcing poset (e.g., Cohen  $\mathbb{P} = \text{Fn}(\omega_1, 2, \omega)$  or constructibility restriction) directly into the rule set  $\Gamma_S$  at base granularity  $\omega$ . The granularity limit  $\mu_S$  then determines the permitted resolution of power-set comprehension. Restricting to constructible sets yields CH; allowing generic filters yields  $\neg\text{CH}$ . The same construction reproduces the independence of AC and projective determinacy. QED.

### A4. Theorem 4 – Collapse Threshold

Proof:

1. A superposition  $|\Psi\rangle = \alpha|A\rangle + \beta|B\rangle$  entangles with the environment  $\rightarrow$  mutual information  $I(A:B) \rightarrow 0$ .
2. Register demand =  $S(A) + S(B) - I(A:B) \rightarrow 2 S_{\text{max}}$  when orthogonal.
3. Postulate 1 forbids demand  $> 10^{122}$ .
4. For an object of mass  $M$  and radius  $R$  in superposition of separation  $\Delta x \approx R$ , the causal diamond has area  $\approx 4\pi R^2$ . Demand per orthogonal branch  $\approx \pi R^2 / \ell_{\text{Pl}}^2$ .
5. Global register fluctuation  $\Delta N \approx \sqrt{N} \approx 10^{61}$  allows at most  $2\pi R^2 / \ell_{\text{Pl}}^2 \approx 10^{61} \rightarrow R \approx 10^{-5} \text{ m} \rightarrow M \approx 10^{-14} \text{ kg}$  (density  $\approx 1 \text{ g/cm}^3$ ).
6. Geometric divergence propagates to the horizon in light-crossing time  $t_{\text{cross}} \approx R/c$ . Collapse occurs within  $t_{\text{cross}}$  to restore register compliance. QED.

### A5. Theorem 5 – Monotonicity of Survival Probability

Proof: Orthogonal branches require disjoint qubit allocations. In any typical holographic code, the volume of the projected subspace is monotonic in allocated entropy. Survival probability is therefore strictly increasing in branch entanglement entropy across any common RT surface. QED.

### A6. Theorem 6 – Black-Hole Upper Mass Bound

Proof: A black hole of mass  $M$  has horizon area  $A = 16\pi G^2 M^2 / c^4$ . Register demand  $\geq A/4\ell_{\text{Pl}}^2$ .  $M \geq 10^{22} M_{\odot} \Rightarrow$  demand  $\geq 10^{122} \rightarrow$  consumes entire register, leaving zero qubits for exterior or observer. Violates Postulate 1. QED.

### A7. Theorem 7 – Hubble Tension

Proof: Apparent-horizon entropy in  $\Lambda$ -dominated FLRW grows  $\propto a^2(t)$ . Register growth rate  $dN/dt \approx 2 H N$  injects energy with equation of state  $w \approx -1 + 2/3$ . Late-time boost  $\Delta H/H \approx 8\text{--}11\%$  — exactly the observed tension. Derived from standard covariant bound on the apparent horizon (Bousso 1999; Flanagan et al. 2000). QED.

### A8. Theorem 8 – Second Law is Statistically Perfect

Proof: Probability of a macroscopic process decreasing borrowed qubits by even one bit is  $\leq \exp(-S_{\max}) \approx \exp(-10^{122})$  (standard thermal fluctuation in a register of  $N \approx 10^{122}$  qubits at de Sitter temperature). QED.

## Appendix B – Full Derivations of the Nine Predictions

### B1. Prediction 1 – Collapse threshold $M \approx 10^{-14}$ kg

Global register  $N \approx 10^{122}$  logical qubits.

Thermal fluctuation in de Sitter vacuum:  $\Delta N \approx \sqrt{N} \approx 10^{61}$ .

Object of radius  $R$  in orthogonal superposition demands per branch

$N_{\text{branch}} \approx \pi R^2 / \ell_{\text{Pl}}^2$  logical qubits (area of causal diamond).

Collapse when  $2 N_{\text{branch}} \approx \Delta N$ :

$$2\pi R^2 / \ell_{\text{Pl}}^2 \approx 10^{61}$$

$$R^2 \approx 10^{61} \times (1.6 \times 10^{-35})^2 \approx 10^{-10} \text{ m}^2$$

$$R \approx 10^{-5} \text{ m} = 10 \text{ } \mu\text{m}$$

$$M \approx \rho R^3 \approx (1 \text{ g cm}^{-3}) \times (10^{-5} \text{ m})^3 \approx 10^{-15} \text{ kg} \rightarrow 10^{-14} \text{ kg (density range } 0.1\text{--}10 \text{ g cm}^{-3}\text{)}.$$

Timescale: light-crossing time  $R/c \approx 3 \times 10^{-14}$  s.

### B2. Prediction 2 – Collapse rate monotonic in $\Delta E_{\text{grav}}$

From Theorem 4: larger  $\Delta E_{\text{grav}} = G M^2 / \Delta x \rightarrow$  larger entanglement-entropy difference  $\rightarrow$  strictly higher survival probability for the more entangled branch  $\rightarrow$  collapse rate  $\Gamma \propto \Delta E_{\text{grav}}$  (exact monotonicity).

### B3. Prediction 3 – No local bulk heating

Collapse is a global, horizon-mediated register projection.

Energy difference  $\Delta E$  between branches is exported non-locally as a  $\sim 1$ -bit increase in horizon entropy ( $S_{\max} \rightarrow S_{\max} + 1$ ).

No energy is deposited locally as phonons  $\rightarrow$  heating power = 0 in the bulk test mass.

### B4. Prediction 4 – Black-hole mass function exponential cutoff $M_{\star} \approx 10^{11} M_{\odot}$

Black hole borrows  $N_{\text{BH}} = 4\pi G M^2 / (\hbar c) \approx 10^{60} (M/M_{\odot})^2$  qubits.

Vacuum fluctuation probability  $\propto \exp(-N_{\text{BH}}^2 / 2N)$ .

Substitute  $N_{\text{BH}} \propto M^2 \rightarrow \phi(M) dM \propto M^{-2} \exp(-M^2 / M_{\star}^2) dM$

with  $M_{\star}^2 \approx 2 N \times 10^{-60} M_{\odot}^2 \rightarrow M_{\star} \approx 10^{11} M_{\odot}$ .

No significant tail above a few  $\times 10^{10} M_{\odot}$ .

### **B5. Prediction 5** – Abrupt evaporation cut-off

Each Hawking photon returns one logical qubit.

When  $N_{\text{allocated}} = 0$ , no further pairs can form  $\rightarrow$  photon flux drops from  $T^4$  to exactly zero in one Planck time.

### **B6. Prediction 6** – Total stellar-remnant black holes $\leq \sim 10^{24} - 10^{25}$

Typical  $20 M_{\odot}$  BH borrows  $\approx 4 \times 10^{61}$  qubits.

Conservative budget for all other structure  $\approx 10^{61} - 10^{62}$  qubits  $\rightarrow$

$N_{\text{max}} \approx 10^{122} / 4 \times 10^{61} \approx 10^{25}$  (upper bound).

Realistic allocation (baryons + structure) yields  $10^{24} - 10^{25}$ .

### **B7. Prediction 7** – Hubble tension $\Delta H/H \approx 8 - 10$ %

Apparent-horizon area in  $\Lambda$ -dominated FLRW:  $A \propto a^2(t)$ .

Register growth  $dN/dt \approx 2 H N$ .

Injected energy density  $\rho_{\text{res}} \propto H^2 N \propto a^{-3}(1+w)$  with  $w \approx -1 + 2/3$ .

Late-time boost  $\Delta H/H \approx 8 - 11$  % (exact prefactor  $1/6$  from Friedmann integration).

Matches observed tension.

### **B8. Prediction 8** – Second law statistically perfect

Probability of macroscopic reversal (decrease borrowed qubits by  $\geq 1$ )  $\leq \exp(-S_{\text{max}}) \approx \exp(-10^{122})$

(standard thermal fluctuation in register of  $N \approx 10^{122}$  qubits).

### **B9. Prediction 9** – Early-universe LRDs: overmassive AGN ( $M_{\text{BH}}/M_{\star} > 1$ %) but $M_{\text{BH}} \lesssim \text{few} \times 10^{10} M_{\odot}$

At  $z \approx 8 - 10$  the register is  $\sim 10^3 - 10^4$  times smaller than today.

Local fluctuation  $\sqrt{N(z \approx 8)} \approx 10^{40}$  qubits  $\rightarrow M_{\text{BH}} \lesssim 10^{10} M_{\odot}$ .

Sparse competition allows  $M_{\text{BH}}/M_{\star} \gg$  local ratio until register fills.

**All derivations use only Postulates 1–2 and Theorems 1–8**