The Gravity–Information Bridge

From Finite-Observer Self-Ignorance to Penrose Objective Reduction

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Abstract

The Ignorant Observer Framework (IOF) and Penrose objective reduction (OR) each assign a timescale to the loss of quantum coherence, and for mesoscopic masses those timescales land in the same 10–100 ms window. This paper is the canonical statement of the *Gravity–Information Bridge*: the single hypothesis under which that coincidence is not a coincidence. The bridge is one proportionality, the *Gravity–Information Bridge Ansatz*,

$$E_G \propto \hbar\kappa_+ \qquad \Longrightarrow \qquad \tau_{\mathrm{OR}} \propto \tau_\kappa,$$

identifying Penrose's gravitational self-energy E_G with $\hbar$ times the observer's information-deficit rate $\kappa = h_{\mathrm{KS}} - C_{\mathrm{eff}} \ln 2$ (rectified to $\kappa_+ = \max(\kappa, 0)$, so the bridge lives only in the chaos-wins regime $\kappa > 0$). A Margolus–Levitin saturation argument supplies one natural calibration, $E_G = (\pi/2)\,\hbar\kappa$, hence $\tau_{\mathrm{OR}} \approx (2/\pi)\,\tau_\kappa \approx 0.64\,\tau_\kappa$; the order-unity coefficient is convention-dependent, equals 1 under a single consistent time convention, and nothing in the bridge rests on its value. The robust, calibration-free content is the proportionality and one falsifiable consequence: because κ depends on the observer's effective tracking capacity C_{eff} while Penrose's geometric self-energy does not, holding mass and geometry fixed and varying C_{eff} should move the *observed* visibility-loss timescale τ_{vis} if the bridge holds — while the geometric Penrose scale $\tau_{\mathrm{OR}}^{\mathrm{geom}}$ stays put — and leave it unmoved if it does not ($\partial\tau_{\mathrm{vis}}/\partial C_{\mathrm{eff}} > 0$). This is the bridge's primary failure criterion. The bridge does not derive gravity from information: the dimensional naturalness of the conversion ($\hbar$ times a rate is an energy) motivates it, but it gains empirical force only from that capacity-dependence test, and is therefore anchored by the BLQC experiment rather than standing on its own. We state the bridge once, derive the calibration, reconcile the coefficient and timescale conventions used elsewhere in the corpus, and delimit precisely what the bridge does and does not claim about gravity and about Penrose OR. The bridge is the most speculative element of the framework and is presented as an ansatz, not a theorem; the optional horizon-thermodynamics and cosmological extensions are referenced, not reproduced. This document is the reference all other IOF papers cite when the bridge is invoked.

1 Why a Bridge Is Needed

Two unrelated lines of argument predict that a coherent superposition stops behaving coherently after a finite time, and for medium-sized masses the two predictions overlap.

On the gravity side, Penrose proposed that a superposition of two appreciably different mass distributions is unstable on its own [1, 2]. The instability has a timescale set by the gravitational self-energy E_G of the difference between the two distributions,

$$\tau_{\mathrm{OR}} \approx \frac{\hbar}{E_G}, \tag{1}$$

a purely geometric quantity: E_G is fixed by mass and separation and says nothing about who, if anyone, is observing.

On the information side, IOF [3] treats the measurement basis as a physical reference variable that a finite observer must actively track [4]. If the tracked dynamics generate information at rate h_{KS} (a Kolmogorov–Sinai entropy rate, in nats/s) while the observer's effective tracking channel has capacity C_{eff} (in bits/s, ultimately bounded by Landauer's principle [5]), then the Data-Rate Theorem of networked control [6] makes the relevant quantity the deficit rate

$$\kappa = h_{\mathrm{KS}} - C_{\mathrm{eff}} \ln 2, \tag{2}$$

and the tracking error variance grows as $\sigma^2(t) = \sigma_0^2 \, e^{2\kappa t}$. In the chaos-wins regime $\kappa > 0$ the basis is lost on the amplitude e-folding timescale

$$\tau_\kappa = \frac{1}{\kappa} = \frac{1}{h_{\mathrm{KS}} - C_{\mathrm{eff}} \ln 2}. \tag{3}$$

This timescale depends on the apparatus's tracking budget, not on the mass.

For mesoscopic parameters the two scales coincide. Penrose/Diósi estimates [1, 7, 8] put τ_{OR} in the 10–100 ms range for masses and geometries of order 10^{-15}–10^{-14} kg over micron separations; the same window is reproduced on the information side by $C_{\mathrm{eff}} \approx 10$ bit/s and $h_{\mathrm{KS}} \approx 50$ nats/s, which give $\kappa = h_{\mathrm{KS}} - C_{\mathrm{eff}} \ln 2 \approx 43\ \mathrm{s}^{-1}$ and an amplitude e-folding time $\tau_\kappa = 1/\kappa \approx 23$ ms; an $\mathcal{O}(1)$ threshold factor $\ln(\sigma_*/\sigma_0)$ then lifts the operational breakdown time to $t_{\mathrm{break}} \approx 50$–70 ms (the distinction is made precise in Table 1) [3, 9]. The original IOF paper recorded this as an unexplained numerical proximity. The question this paper answers is whether the proximity can be promoted from coincidence to consequence — and at what epistemic cost.

The answer offered here is a single hypothesis. It is deliberately narrow: it does not modify unitary quantum mechanics, does not posit a physical collapse field, and does not derive Newton's constant or any mass. It asserts only that one energy and one rate are proportional. Everything else in this paper is the unpacking, calibration, and falsification of that one assertion.

Scope and status. The bridge is the most speculative single move in the IOF corpus, and it is fenced as such throughout. This document defines the lab-scale bridge and its relationship to Penrose OR. Two further layers built on the bridge — an optional horizon-thermodynamics identification ($h_{\mathrm{KS}} \leftrightarrow \kappa_{\mathrm{geo}}$ via the Maldacena–Shenker–Stanford chaos bound [10] and the Unruh temperature) and the cosmological generalization ($\kappa \to \kappa_{\mathrm{global}}$, with a MOND-scale reading) — are developed in *The Creation of Duality* [11] and the *Cosmological Notes*, and are referenced here rather than reproduced. They are extensions *of* the bridge; the bridge itself is the proportionality of Section 3.

Where the speculation enters. It is worth marking three levels explicitly, so the reader knows precisely which step is conjectural and which is standing on established ground:

1. **Established background.** Penrose objective reduction and gravitational self-energy [1, 2], and the Margolus–Levitin bound [12]. Standard physics, used as given.

2. **IOF/BLQC hypothesis.** Finite-capacity basis tracking produces the deficit rate $\kappa = h_{\mathrm{KS}} - C_{\mathrm{eff}} \ln 2$ and a capacity-dependent visibility law; this is the framework's experimentally testable core [3, 9].
3. **The bridge ansatz.** The single new move of this paper: $E_G \propto \hbar\kappa$. All of the speculation lives at this level and nowhere else.

The bridge sits *above* the BLQC module, not beside it. Its dimensional naturalness — $\hbar$ times a rate is an energy — makes it a reasonable object to write down, but naturalness motivates a bridge, it does not establish one. The bridge therefore carries no independent evidential weight: it acquires empirical force only if the BLQC-style capacity-dependence of Level 2 is actually observed, and it fails the moment that dependence is shown absent (Section 6). In the framework stack it is a falsifiable extension that leans *downward* onto the BLQC test, not *upward* into the interpretive layer of *The Creation of Duality* [11].

2 The Two Sides in Their Own Terms

Before joining them, each side is stated cleanly, so that the bridge is visibly an added hypothesis and not a hidden assumption in either.

2.1 The gravity side: Penrose objective reduction

Penrose OR is the proposal that the superposition principle fails for gravitationally significant mass differences, with no observer required. For a superposition of two stationary mass distributions, let E_G be the gravitational self-energy of the difference between them — equivalently, the energy uncertainty associated with the ill-definedness of the two spacetimes' time-translation Killing fields. The lifetime of the superposition is

$$\tau_{\mathrm{OR}} \approx \frac{\hbar}{E_G}, \qquad E_G \sim \frac{Gm^2}{R} \text{ (rigid body, separation} \gtrsim R), \qquad \tau_{\mathrm{OR}} \sim \frac{\hbar R}{Gm^2}. \tag{4}$$

The content for our purposes is structural: (i) the collapse time is the reciprocal of an energy, Eq. (1); and (ii) that energy is set entirely by mass and geometry. Penrose OR contains no free observer-side parameter. The Diósi–Penrose model [7] gives the same scaling with a smeared mass density, and sits within the broader family of objective-collapse models [8].

2.2 The information side: IOF tracking loss

IOF makes no statement about mass. It says that recording which outcome occurred in which basis requires the observer-apparatus system to track a physical reference variable whose generating dynamics have positive instability rate h_{KS}, using a channel of finite capacity C_{eff}. The governing scalar is the deficit rate κ of Eq. (2), with two regimes:

- $\kappa < 0$ (*capacity-wins*): the channel outruns the instability, basis uncertainty is suppressed, and standard quantum predictions are recovered;
- $\kappa > 0$ (*chaos-wins*): basis uncertainty grows as $e^{2\kappa t}$ and coherence is lost on the timescale $\tau_\kappa = 1/\kappa$, Eq. (3).

The observable consequence is a visibility law $V_{\text{measured}} = V_{\text{QM}}\, e^{-\sigma^2/2}$ with $\sigma^2(t) = \sigma_0^2 e^{2\kappa t}$, giving a double-exponential "breakdown" at $t_{\text{break}} \propto 1/\kappa$ [9, 13]. The scalar κ is called the *self-ignorance rate* on the observer side and throughout the rest of the corpus; in this paper, because it is being mapped to a gravitational energy, the same scalar is called the *information-deficit rate*. The two names denote one quantity, Eq. (2).

Crucially, κ contains C_{eff}: the IOF timescale is a function of the observer's tracking budget. This is the single structural difference from the gravity side, and it is the hinge on which the entire bridge — and its falsification — turns.

3 The Bridge Ansatz

The bridge is a single proportionality between the two sides' defining quantities.

Definition 3.1 (Gravity–Information Bridge Ansatz)**.** The gravitational self-energy that sets the Penrose collapse time is proportional to $\hbar$ times the observer's information-deficit rate:

$$\boxed{E_G \;\propto\; \hbar\,\kappa_+ \;=\; \hbar\,\max(h_{\text{KS}} - C_{\text{eff}} \ln 2,\, 0)} \tag{5}$$

The bridge is defined only in the chaos-wins regime $\kappa > 0$, where a positive deficit rate exists to convert into an energy. The rectified form $\kappa_+ \equiv \max(\kappa, 0)$ is written explicitly so that in capacity-wins regimes ($\kappa \leq 0$) the *mapped* deficit energy vanishes, $E_{\text{def}} \to 0$, rather than turning negative. The quantity that vanishes is the information-deficit energy the bridge maps onto E_G, not the gravitational self-energy of the mass distribution itself, which is unaffected; there is no negative deficit energy in the framework, and a non-positive κ simply means there is no untracked information left to carry one. Throughout the rest of the paper κ is taken in the chaos-wins regime, so $\kappa_+ = \kappa > 0$. Equivalently, writing $E_G = \alpha_{\text{geo}}\,\hbar\kappa$ for a dimensionless order-unity constant α_{geo}, the Penrose and IOF timescales are proportional,

$$\tau_{\text{OR}} = \frac{\hbar}{E_G} = \frac{1}{\alpha_{\text{geo}}}\frac{1}{\kappa} = \frac{1}{\alpha_{\text{geo}}}\tau_\kappa \qquad \Longrightarrow \qquad \tau_{\text{OR}} \propto \tau_\kappa. \tag{6}$$

Three things about Definition 3.1 must be stated immediately, because the rest of the corpus depends on them being understood the same way everywhere.

1. **It is an ansatz, not a theorem.** Eq. (5) is a posited mapping from an information rate to an energy scale. It is not derived from general relativity, and it does not follow from IOF's own axioms. It is an additional hypothesis, and it is the most speculative hypothesis in the framework.
2. **The robust claim is the proportionality.** What the bridge asserts, and what every downstream result actually uses, is $E_G \propto \hbar\kappa$ and hence $\tau_{\text{OR}} \propto \tau_\kappa$. The value of α_{geo} is a calibration, not part of the claim (Section 4).
3. **It is falsifiable through C_{eff}.** Because the right-hand side of Eq. (5) contains C_{eff} and the Penrose left-hand side does not, the bridge makes a prediction that ordinary OR does not (Section 6). This is what keeps it from being mere numerology.

The remainder of the paper (i) supplies one principled calibration of α_{geo} from the Margolus–Levitin bound, (ii) fixes the timescale and coefficient conventions so the corpus speaks with one voice, (iii) states the falsifiable prediction and its primary failure criterion, and (iv) delimits the relationship to Penrose OR.

4 Calibration: the Energy of Untracked Information

The proportionality of Eq. (5) fixes only the *form*. A natural physical argument fixes one value of the constant α_{geo}: identify the gravitational self-energy with the energy that a maximally efficient tracker would need to keep up with the part of the dynamics it is failing to track. The full statement is the Correspondence Lemma of Appendix A; here is its content in one line of physics.

The Margolus–Levitin bound [12, 14] states that a system with mean energy E above its ground state passes through orthogonal (perfectly distinguishable) states at a rate of at most

$$r_{\max} \;=\; \frac{2E}{\pi\hbar} \qquad \text{(orthogonal transitions per unit time).} \tag{7}$$

If one orthogonal transition is identified with one nat of tracked information — a calibration choice, not a theorem — then sustaining a tracking/instability rate r (nats/s) requires energy $E(r) = (\pi\hbar/2)\,r$. Apply this to the two rates of Eq. (2): the total instability burden h_{KS} and the tracked part $C_{\text{eff}} \ln 2$. The *untracked* part is the deficit, and its energetic cost is

$$E_{\text{deficit}} \;=\; \frac{\pi\hbar}{2}\,h_{\text{KS}} - \frac{\pi\hbar}{2}\,(C_{\text{eff}}\ln 2) \;=\; \frac{\pi\hbar}{2}\,(h_{\text{KS}} - C_{\text{eff}}\ln 2) \;=\; \frac{\pi\hbar}{2}\,\kappa. \tag{8}$$

Identifying this deficit energy with the Penrose self-energy gives the *ML-saturated calibration* of the ansatz,

$$\boxed{E_G \;=\; \frac{\pi}{2}\,\hbar\,\kappa, \qquad \alpha_{\text{geo}} = \frac{\pi}{2} \approx 1.57 \quad \text{(ML-saturated calibration)}} \tag{9}$$

and, through $\tau_{\text{OR}} = \hbar/E_G$,

$$\tau_{\text{OR}} \;=\; \frac{\hbar}{(\pi/2)\hbar\kappa} \;=\; \frac{2}{\pi}\,\frac{1}{\kappa} \;=\; \frac{2}{\pi}\,\tau_\kappa \;\approx\; 0.64\,\tau_\kappa \qquad \text{(ML-saturated calibration).} \tag{10}$$

4.1 The order-unity coefficient, and why the corpus quotes two of them

Equation (10) is the source of the factor 0.64 that appears in *The Creation of Duality* [11] and in Appendix B of the experimental protocol [15]. The *Cosmological Notes* instead state the bridge as $\tau_{\text{OR}} \approx \tau_\kappa$, with coefficient 1. These are not in conflict, and this subsection is the canonical reconciliation.

The factor $2/\pi$ in Eq. (10) is not a property of the information deficit. It is the ratio between two time conventions: the Penrose time $\hbar/E_G$ on one side and the Margolus–Levitin orthogonalization time $\pi\hbar/(2E_G)$ implicit in the calibration on the other. If a single convention is applied consistently on both sides — either Penrose-time throughout, or ML-time throughout, or simply $E_G \sim \hbar\kappa$ with $\alpha_{\text{geo}} = 1$ on both — the coefficient is exactly 1 and

$$\tau_{\text{OR}} \;=\; \tau_\kappa \qquad (\alpha_{\text{geo}} = 1,\ \text{single consistent convention}). \tag{11}$$

The defensible, calibration-independent statement is therefore

$$\boxed{\tau_{\text{OR}} \;=\; \mathcal{O}(1)\,\tau_\kappa} \tag{12}$$

with 0.64 and 1 bracketing the natural conventions. **This paper adopts the proportionality $\boldsymbol{\tau_{\text{OR}} \propto \tau_\kappa}$ of Eq. (6) as the canonical statement of the bridge**, and quotes $0.64\,\tau_\kappa$ only as "the ML-saturated calibration," Eq. (10). No empirical claim in the corpus depends on distinguishing 0.64 from 1: both reduce to "the two timescales are proportional, with an order-unity constant." Where a single number is wanted for an order-of-magnitude estimate, use Eq. (10); where rigor is wanted, use Eq. (12).

Remark 4.1 (What Margolus–Levitin does and does not supply)**.** The bound (7) licenses the *form* "energy is set by a rate," and on dimensional grounds $E_G \sim \hbar\kappa$ follows immediately. What it does *not* supply is the constant: the step from Eq. (7) to Eq. (8) uses the calibration "one orthogonal transition $\equiv$ one nat" and the saturation assumption that the tracker runs at the ML bound. Relaxing saturation by an efficiency factor $\eta \leq 1$ replaces Eq. (10) by $\tau_{\mathrm{OR}} \sim (2/\pi)\,\eta\,\tau_\kappa$, which is again $\mathcal{O}(1)\,\tau_\kappa$. The coefficient is a calibration choice; the proportionality is the bridge claim — itself an ansatz, not established physics (Section 3).

5 Which Clock Enters the Bridge

The IOF dynamics define several timescales that differ by order-unity factors, and the corpus has occasionally labeled the same 10–100 ms scale in more than one way. Because the bridge equates a timescale with τ_{OR}, the canonical paper must say exactly which clock appears in Eqs. (6)–(12). It is $\tau_\kappa = 1/\kappa$, the amplitude e-folding time. Table 1 fixes the notation for the whole corpus.

Symbol	Definition	Role
τ_κ	$\dfrac{1}{\kappa}$	Amplitude e-folding time ($\sigma \propto e^{\kappa t}$). **The clock in the bridge.**
τ_{var}	$\dfrac{1}{2\kappa}$	Variance e-folding time ($\sigma^2 \propto e^{2\kappa t}$).
t_*	$\dfrac{1}{\kappa}\ln\dfrac{\sigma_*}{\sigma_0}$	Operational threshold-crossing time; $= \tau_\kappa$ up to an $\mathcal{O}(1)$ log factor.
t_{break}	$\propto \dfrac{1}{\kappa}$	Measured visibility-breakdown time; an instance of t_*.
τ_{SK}	threshold-crossing t_*	"Self-knowledge" scale used in the biological supplement; a threshold variant of τ_κ, *not* the bare $1/\kappa$ clock.

Table 1: Timescales of the IOF dynamics. The bridge $\tau_{\mathrm{OR}} \propto \tau_\kappa$ is stated for the amplitude e-folding time $\tau_\kappa = 1/\kappa$. The perceptual/biological scale written τ_{SK} elsewhere is a threshold-crossing variant t_*, differing from τ_κ by the $\mathcal{O}(1)$ logarithmic factor $\ln(\sigma_*/\sigma_0)$; it is therefore also $\mathcal{O}(1)\,\tau_\kappa$, consistent with Eq. (12), but it is not the symbol that appears in the boxed bridge relations.

Two notational points, recorded here so downstream papers need not re-litigate them:

- **τ_{OR} is compared to τ_κ, never to τ_{SK} directly.** The biological τ_{SK} enters only through $\tau_{\mathrm{SK}} = \mathcal{O}(1)\,\tau_\kappa$; writing "$\tau_{\mathrm{OR}} \approx \tau_{\mathrm{SK}}$" is loose shorthand for the chain $\tau_{\mathrm{OR}} \propto \tau_\kappa$, $\tau_{\mathrm{SK}} = \mathcal{O}(1)\,\tau_\kappa$, and should be read that way.
- **Subscripts on κ.** This paper uses the bare κ of Eq. (2). The experimental protocol [15] writes the same quantity as κ_{info} when it must be distinguished from an empirical regressor; *The Creation of Duality* [11] additionally uses κ_{geo} for a geometric surface-gravity rate and $\kappa_P \equiv 1/t_P$ for the Planck rate. Only $\kappa = h_{\mathrm{KS}} - C_{\mathrm{eff}}\ln 2$ enters the bridge of Definition 3.1; the others belong to the optional horizon and Planck layers and do not appear here.

6 What the Bridge Predicts, and How It Fails

The bridge would be empty if it only re-described an existing number. Its content is that it makes a prediction Penrose OR cannot, and the prediction follows from the one structural asymmetry of Section 3: κ contains C_{eff}, while E_G does not.

It is essential to keep two timescales notationally distinct, because conflating them is what makes the prediction sound like a contradiction. Let $\tau_{\text{OR}}^{\text{geom}} = \hbar/E_G^{\text{geom}}$ be the *Penrose geometric scale*, fixed by mass and geometry and carrying no observer-side parameter. Let $\tau_{\text{vis}}(C_{\text{eff}})$ be the *observed* coherence/visibility-loss time — the IOF tracking-loss scale, $\tau_{\text{vis}} \approx \tau_\kappa = 1/\kappa$ up to the $\mathcal{O}(1)$ threshold factor of Table 1. The bridge does *not* redefine $\tau_{\text{OR}}^{\text{geom}}$; it identifies τ_{vis} with $\tau_{\text{OR}}^{\text{geom}}$ *at the apparatus's intrinsic tracking floor*, and the falsifiable content is what happens when C_{eff} is engineered above that floor.

Proposition 6.1 (Capacity-dependence prediction)**.** *Under the bridge, the* observed *visibility-loss time inherits the C_{eff}-dependence of κ, while the Penrose geometric scale does not:*

$$\tau_{vis}(C_{\mathit{eff}}) \;\approx\; \tau_\kappa \;=\; \frac{1}{h_{KS} - C_{\mathit{eff}}\ln 2} \quad\Longrightarrow\quad \frac{\partial\,\tau_{vis}}{\partial\,C_{\mathit{eff}}} \;>\; 0, \qquad \mathit{whereas} \qquad \frac{\partial\,\tau_{OR}^{geom}}{\partial\,C_{\mathit{eff}}} \;=\; 0. \tag{13}$$

Increasing the observer's useful tracking capacity C_{eff} lengthens *the observed coherence time. Standard Penrose OR predicts that the observed coherence-loss time simply* is τ_{OR}^{geom}*, and so does not move with the apparatus's readout/control budget at all. The two frameworks therefore disagree not about the value of the Penrose scale — which both hold fixed — but about whether the* measured *coherence-loss time tracks it or departs from it as C_{eff} is varied.*

This is a genuine experimental fork, and it inverts the sign of the familiar effect: ordinary thermal decoherence gets *faster* as one couples more strongly to the apparatus, whereas Eq. (13) says a more capable tracker holds coherence *longer*. The discriminator is therefore not merely a magnitude but a sign.

The experiment. The natural setting is a QGEM-class matter-wave interferometer [16], which exposes both knobs: a mesoscopic mass on one side and a real control/readout loop on the other. The protocol is [9, 15]:

1. Hold mass, separation, geometry, temperature, readout noise floor, and plant dynamics fixed, so the gravity-side τ_{OR} of Eq. (1) cannot move.
2. Vary only the observer's effective tracking capacity C_{eff} (equivalently, throttle the useful information rate of the control loop).
3. Measure whether the visibility-loss timescale moves with κ, or stays pinned by mass geometry.

The verdicts. The outcomes are clean, and they are the same fork stated in the foundational extension [4]:

- **No C_{eff}-dependence**, once ordinary confounds are controlled: the observer-side channel is absent and *the bridge is falsified.* This is the primary failure criterion — *Effective-Capacity Independence.* The retrospective screen of *Forensic Signatures* [13] is the model-agnostic version of the same test.

- **The timescale moves with κ at fixed mass geometry**: the observer's tracking capacity is part of what sets the classicalization boundary, and the IOF mechanism is physically serious rather than interpretive.
- **Co-variation**: in a design that varies both mass and capacity, if the gravity scale and the κ scale track together, the strong reading — that gravitational collapse and finite-observer tracking loss are two faces of one boundary — becomes worth taking seriously.

The bridge thus converts a foundational question into an experimental one: *is the classicalization boundary governed only by mass geometry, or also by the finite tracking capacity of the observer?* The coefficient α_{geo} never enters this test; only the sign and the C_{eff}-dependence do. That is the point of resting the bridge on a proportionality rather than a number.

If IOF succeeds but the bridge fails. A possible outcome is that IOF/BLQC succeeds while the Gravity–Information Bridge fails. In that case the measured visibility-loss time would still scale with the information-deficit rate $\kappa = h_{\text{KS}} - C_{\text{eff}} \ln 2$, confirming finite-capacity basis tracking as a real observer-side mechanism, but the inferred scale $\hbar\kappa_+$ would not coincide with Penrose's gravitational self-energy E_G beyond accidental order-of-magnitude overlap. The bridge would then be rejected as a gravitational interpretation of the BLQC signal, not as a refutation of IOF itself. The numerical proximity between τ_κ and $\tau_{\text{OR}}^{\text{geom}}$ would remain a coincidence; the IOF visibility law would stand alone as a capacity-controlled account of classical record formation, while Penrose OR and the optional horizon/cosmological extensions would lose their role in the framework.

7 Relationship to Penrose Objective Reduction

Because every other paper that mentions Penrose OR will point here, this section states precisely what is shared, what differs, and what is *not* being claimed.

7.1 What is shared

Both frameworks write a classicalization time as the reciprocal of an energy, $\tau \approx \hbar/E$, and both place the mesoscopic boundary in the same 10–100 ms window. The bridge takes Penrose's functional form, Eq. (1), at face value and supplies a second reading of the energy $E = E_G$ that appears in it.

7.2 What differs

	Penrose OR	**IOF + bridge**
Origin of the energy E_G	Gravitational self-energy of the mass difference	Energetic cost of *untracked* information, $E_G \propto \hbar\kappa$
What sets the observed time	Mass and geometry only ($= \tau_{\text{OR}}^{\text{geom}}$)	Mass geometry at the floor *and* capacity C_{eff} (τ_{vis})
Status of collapse	Objective dynamical reduction (modifies QM)	No modification of unitary QM; apparent collapse is loss of trackability
Free observer parameter	None	C_{eff} (the falsifiable handle)
Sign of capacity effect	0 (no movement)	$\partial\tau_{\text{vis}}/\partial C_{\text{eff}} > 0$

Table 2: Penrose OR versus IOF under the Gravity–Information Bridge. The frameworks agree on the form $\tau \approx \hbar/E_G$ and the mesoscopic window; they differ on what E_G *is* and on whether the collapse time can depend on the observer.

The ontological difference is worth stating plainly: Penrose OR is a modification of quantum mechanics, in which the superposition principle genuinely fails for large masses. IOF is not. IOF keeps unitary evolution exact and relocates "collapse" to the observer's inability to keep tracking the basis. The bridge does not import Penrose's dynamical reduction into IOF; it imports Penrose's *timescale formula* and reinterprets the energy in it. An experiment confirming the bridge would not show that gravity collapses the wavefunction; it would show that the scale at which coherence becomes untrackable coincides with the scale Penrose computes from gravity — which is a statement about a boundary, not about a force.

7.3 What is *not* claimed

- **No derivation of mass or of G.** The bridge maps E_G to $\hbar\kappa$; it does not derive E_G from m and R, nor Newton's constant from anything. "Mass as a tracking artifact" is interpretive gloss in *The Creation of Duality* [11], not a forward-prediction step.
- **No replacement of Penrose OR.** The bridge is parasitic on Eq. (1): it uses the Penrose/Diósi estimate of E_G as the gravity-side anchor and adds an information-side reading. It is a correspondence, not a competitor.
- **No claim that the coincidence is, by itself, evidence.** Until the C_{eff}-dependence of Proposition 6.1 is measured, the numerical proximity remains suggestive only. The biological-scale appearance of the same window [4] is another use of the same κ-scaling, not an independent confirmation.
- **No commitment to the optional layers.** The horizon-thermodynamics identification ($h_{\text{KS}} \leftrightarrow \kappa_{\text{geo}}$ at saturation, via [10] and the Unruh temperature) and the Jacobson-style thermodynamic-gravity reading [17] are developed in [11] as *optional* extensions that strengthen the motivation but are not required for the lab-scale bridge defined here. The core bridge is Eq. (5) and nothing more.

7.4 Two objections worth meeting directly

An objective energy cannot equal an apparatus-dependent rate. Penrose's E_G is observer-independent — fixed by mass and geometry — whereas $\kappa = h_{\mathrm{KS}} - C_{\mathrm{eff}} \ln 2$ contains the apparatus's tracking budget C_{eff}. How can the two be proportional? This is the sharpest objection, and the reply is that the bridge does not equate an objective energy with an apparatus knob for *all* apparatuses. The mass-set gravitational scale is not removed. What the bridge claims is narrower: the threshold at which a *finite observer* can no longer track the superposition's basis is set by κ, and for an apparatus operating at its intrinsic tracking floor this observer-registered threshold coincides with Penrose's E_G. Engineering C_{eff} upward then moves the observer-registered threshold away from that floor while the mass-set E_G stays put. The bridge is thus a statement about the *tracked* phase reference, not a claim that geometry itself is apparatus-dependent — and the gap between the objective floor and the engineered threshold is exactly the measurable C_{eff}-dependence of Proposition 6.1. An objective geometry and a capacity-dependent observed threshold are not in contradiction; the bridge is precisely the assertion that the two meet at the floor.

Is this just decoherence or control noise? No, and the distinction is built to be operational rather than rhetorical. The claim is not ordinary environmental decoherence: it is a capacity-dependent visibility ceiling that survives *after* thermal coupling, readout noise, and plant dynamics have been calibrated and held fixed (step 1 of the protocol in Section 6). Two features separate it from a noise artefact. First, the *sign*: stronger environmental coupling shortens coherence, whereas increasing useful tracking capacity *lengthens* it ($\partial\tau/\partial C_{\mathrm{eff}} > 0$), so a positive capacity-dependence cannot be manufactured by adding noise. Second, the *functional form*: the predicted decay is the double-exponential $V = V_{\mathrm{QM}}\, e^{-\sigma_0^2 e^{2\kappa t}/2}$, not the single-exponential of Markovian dephasing, and the adversarial identifiability and noise-mimic tests of *Forensic Signatures* [13] are designed precisely to separate the two. If the effect can be reproduced by recalibrating noise at fixed C_{eff}, the bridge claims nothing.

8 Epistemic Status, in One Place

So that no downstream paper has to re-derive the hedging, the bridge's standing is summarized here.

- **An ansatz.** Eq. (5) is posited, not proven. It is the most speculative element of the IOF corpus.
- **A proportionality, not a number.** The content is $E_G \propto \hbar\kappa$, $\tau_{\mathrm{OR}} \propto \tau_\kappa$. The coefficient α_{geo} is an order-unity calibration: $\pi/2$ under Margolus–Levitin saturation, 1 under a single consistent convention, $\mathcal{O}(1)$ in general (Eqs. (10)–(12)).
- **Falsifiable.** The primary failure criterion is Effective-Capacity Independence: if the coherence-loss timescale does not move with calibrated C_{eff} at fixed mass geometry, the bridge is broken (Proposition 6.1).
- **The Margolus–Levitin step licenses the form, not the constant.** "One transition $\equiv$ one nat" and ML saturation are calibration choices; the dimensional content $E_G \sim \hbar\kappa$ is robust to them.
- **The optional layers are optional.** Horizon thermodynamics, the Planck-rate reparameterization $G = c^5/(\hbar\kappa_P^2)$, the cosmological globalization $\kappa \to \kappa_{\mathrm{global}}$, and all Vedantic readings live in [11] and the *Cosmological Notes*, and are not part of the claim defended here.

Structural Correspondence 8.1 (for readers of the interpretive layer). In *The Creation of Duality*, the same proportionality $E_G \propto \hbar\kappa$ is read as a statement that "the force that binds is identical to the rate that liberates." That reading is an explicitly labeled Vedāntic gloss on Eq. (5), carrying no additional physical commitment. It is recorded there, not here; this paper is the physics-only reference.

9 Conclusion

The Gravity–Information Bridge is one equation with a clear job: it explains why the IOF tracking-loss timescale and the Penrose objective-reduction timescale meet in the same mesoscopic window, by positing that Penrose's gravitational self-energy is $\hbar$ times the observer's information-deficit rate, $E_G \propto \hbar\kappa_+$ (chaos-wins regime only). From this single proportionality follow the timescale correspondence $\tau_{\rm OR} \propto \tau_\kappa$ (with an order-unity coefficient that is 0.64 under Margolus–Levitin saturation and 1 under a consistent convention), and one falsifiable prediction that Penrose OR cannot make: that increasing the observer's tracking capacity at fixed mass geometry lengthens the *observed* visibility-loss time, $\partial\tau_{\rm vis}/\partial C_{\rm eff} > 0$, while the geometric Penrose scale $\tau_{\rm OR}^{\rm geom}$ stays fixed. The bridge is an ansatz and the most speculative move in the framework, but it is an honest one — it rests on a proportionality rather than a coefficient, and it lives or dies by a measurement. That measurement is the one BLQC already targets: at fixed mass distribution and geometry, standard Penrose OR predicts no dependence on engineered $C_{\rm eff}$, the bridge predicts such dependence, and this single contrast is the decisive experimental distinction. The bridge therefore stands or falls with BLQC — it adds a gravitational reading to the BLQC signal and claims nothing if that signal is absent. Whether the classicalization boundary is set by mass alone or also by the finite capacity of the observer is now a question an experiment can answer; this paper defines the bridge that makes the question sharp.

A Correspondence Lemma: E_G as the Energy of Untracked Information

This appendix is the canonical home of the calibration sketched in Section 4. It is an *epistemic consistency condition within the bridge ansatz*, not an ontological derivation of a gravitational field. It shows that, given the ansatz $E_G \propto \hbar\kappa$, the Margolus–Levitin bound fixes one natural value of the constant.

Lemma A.1 (Energy of untracked information)**.** *Adopt the calibration that one orthogonal (perfectly distinguishable) state transition carries one nat of information. Then, at Margolus–Levitin saturation, the energy required to track a process generating information at rate r (nats/s) is $E(r) = (\pi\hbar/2)\,r$, and the energy of the information a finite observer fails to track is*

$$E_{deficit} = \frac{\pi\hbar}{2}\,\kappa, \qquad \kappa = h_{KS} - C_{eff}\ln 2 \quad (\kappa > 0). \tag{14}$$

Identifying $E_G = E_{deficit}$ yields $E_G = (\pi/2)\,\hbar\kappa$, i.e. $\alpha_{geo} = \pi/2$.

Derivation. The Margolus–Levitin theorem [12, 14] bounds the rate of orthogonal evolution of a system with mean energy E above its ground state by $r_{\max} = 2E/(\pi\hbar)$, Eq. (7). Inverting at saturation, a sustained orthogonalization (hence, by the calibration, information) rate r costs energy

$$E(r) = \frac{\pi\hbar}{2}\,r. \tag{15}$$

The instability the observer must track is generated at rate h_{KS}; the observer's channel removes uncertainty at rate $C_{\mathrm{eff}} \ln 2$ (converting bits/s to nats/s). The corresponding energies are $E_{\mathrm{total}} = (\pi\hbar/2)h_{\mathrm{KS}}$ and $E_{\mathrm{tracked}} = (\pi\hbar/2)(C_{\mathrm{eff}} \ln 2)$, and the untracked remainder is

$$E_{\mathrm{deficit}} = E_{\mathrm{total}} - E_{\mathrm{tracked}} = \frac{\pi\hbar}{2}\,(h_{\mathrm{KS}} - C_{\mathrm{eff}} \ln 2) = \frac{\pi\hbar}{2}\,\kappa. \tag{16}$$

Setting $E_G = E_{\mathrm{deficit}}$ gives $E_G = (\pi/2)\hbar\kappa$. Through Penrose's $\tau_{\mathrm{OR}} = \hbar/E_G$,

$$\tau_{\mathrm{OR}} = \frac{2}{\pi}\frac{1}{\kappa} = \frac{2}{\pi}\tau_\kappa \approx 0.64\,\tau_\kappa. \tag{17}$$

□

Remark A.2 (Why only the form survives)**.** Two calibration choices enter the lemma: "one transition ≡ one nat" and saturation of the bound. Neither is forced. Replacing saturation by efficiency $\eta \le 1$ scales the result to $\tau_{\mathrm{OR}} \sim (2/\pi)\eta\,\tau_\kappa$; using a single time convention on both sides sends $\alpha_{\mathrm{geo}} \to 1$. In every case the surviving statement is $E_G \propto \hbar\kappa$ and $\tau_{\mathrm{OR}} = \mathcal{O}(1)\,\tau_\kappa$ — the form, not the constant. This is why the main text rests the bridge on the proportionality, Eqs. (5) and (12), and treats $\pi/2$ as one calibration among the natural choices.

Relation to the horizon layer (optional). Lemma A.1 reaches $E_G \propto \hbar\kappa$ *without* invoking horizons: it needs only the Margolus–Levitin bound and the deficit rate. A separate, optional argument in [11] reaches a compatible identification from horizon thermodynamics, by saturating the Maldacena–Shenker–Stanford chaos bound [10] $h_{\mathrm{KS}} \le 2\pi k_B T/\hbar$ at the Unruh temperature $T = \hbar\kappa_{\mathrm{geo}}/(2\pi k_B)$, which gives $h_{\mathrm{KS}} = \kappa_{\mathrm{geo}}$ and hence $\kappa \approx \kappa_{\mathrm{geo}} - C_{\mathrm{eff}} \ln 2$. That layer connects κ to a geometric surface-gravity rate and is the route to GR scales; it is not required for, and is logically downstream of, the lab-scale bridge defined in this paper.

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