Prospective Tests of Bandwidth-Limited Observer Dynamics

Experimental Protocol for the Ignorant Observer Framework

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May 2026
Version 2.3

DOI: 10.17605/OSF.IO/2QJNE

Abstract

This document specifies a single prospective experiment: a mesoscopic visibility-loss test in the regime where Bandwidth-Limited Quantum Control (BLQC) and Penrose Objective Reduction (OR) can predict comparable timescales. Penrose OR assigns the loss timescale to gravitational self-energy, hence to mass geometry. BLQC assigns the loss timescale to finite-rate basis-reference tracking, hence to the deficit

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

where h_{KS} is the entropy-rate or instability proxy of the relevant basis-reference dynamics and C_{eff} is the useful information rate available to track or stabilize that reference.

The core question is therefore direct: at fixed thermal, readout, pulse, latency, and plant conditions, does the measured visibility-loss timescale follow mass/separation as Penrose OR predicts, or does it move with C_{eff} and h_{KS} as BLQC predicts? The protocol defines the required platform, control variables, confound controls, statistical tests, and decision rules for that discrimination.

Scope of this protocol. This protocol specifies a prospective Penrose-overlap test within the Ignorant Observer Framework (IOF). BLQC is the finite-rate basis-tracking mechanism evaluated here. The experiment is designed to distinguish a Penrose-style mass-geometry timescale from a BLQC-style capacity/instability timescale in the same mesoscopic apparatus.

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1 The Experimental Question

The experiment targets the regime in which a mesoscopic quantum system exhibits a visibility-loss or collapse-like timescale of order milliseconds to hundreds of milliseconds. This is the regime where Penrose OR can become relevant for sufficiently massive or spatially separated superpositions, and where BLQC can also predict loss if the apparatus reference frame is maintained by a finite-rate tracking loop close to its instability boundary.

The decisive question is whether, in a mesoscopic experiment where Penrose OR is a serious candidate mechanism, the loss timescale follows:

- **mass geometry**, as Penrose OR predicts; or
- **basis-reference tracking capacity**, as BLQC predicts.

The same apparatus must expose both sets of variables: the mass-geometry variables entering the Penrose estimate and the basis-reference variables entering the BLQC estimate.

2 Competing Predictions

2.1 Penrose Objective Reduction

Penrose OR predicts a collapse-like timescale set by gravitational self-energy:

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

where E_G depends on the mass distribution mismatch between the branches of a spatial superposition. In simplified scaling form, for mass m and separation s,

$$\tau_{\rm OR} \sim \frac{\hbar s}{G m^2}, \tag{2}$$

up to geometry-dependent factors and saturation behavior at large separations.

Penrose OR therefore predicts that the loss timescale should change when mass, separation, or mass distribution changes, and should not have a leading dependence on the classical controller's useful basis-tracking capacity once ordinary experimental confounds are controlled.

2.2 BLQC

BLQC treats the measurement basis as a physical reference variable $\theta(t)$ implemented by apparatus: phase reference, local oscillator, pulse axis, field direction, path-separation reference, timing system, or equivalent control state. If this reference has instability or entropy-rate proxy $h_{\rm KS}$ and is tracked through useful capacity $C_{\rm eff}$, BLQC defines

$$\kappa = h_{\rm KS} - C_{\rm eff} \ln 2. \tag{3}$$

In the chaos-wins regime ($\kappa > 0$), BLQC predicts growth of unresolved basis uncertainty:

$$\sigma_\theta^2(t) = \sigma_0^2 e^{2\kappa t}. \tag{4}$$

If visibility is reduced by Gaussian basis uncertainty, then

$$V(t) = \exp\left[-\frac{1}{2}\sigma_0^2 e^{2\kappa t}\right]. \tag{5}$$

For a chosen threshold V_*, the breakdown time is

$$t_{\text{break}} = \frac{1}{2\kappa} \ln\left(\frac{-2\ln V_*}{\sigma_0^2}\right). \tag{6}$$

BLQC therefore predicts that, at fixed mass geometry and fixed environmental controls, increasing useful C_{eff} delays loss, while increasing h_{KS} accelerates loss.

2.3 Discrimination Table

Controlled change	**Penrose OR**	**BLQC**
Increase mass at fixed C_{eff}, h_{KS}, and separation	Faster loss	No leading BLQC change unless reference dynamics also change
Increase separation at fixed C_{eff}, h_{KS}, and mass	Geometry-dependent OR shift	No leading BLQC change unless reference dynamics also change
Increase C_{eff} at fixed mass, separation, temperature, and readout	No leading OR change	Delayed loss
Increase h_{KS} at fixed mass, separation, temperature, and readout	No leading OR change	Faster loss

The primary discriminator is not the absolute timescale. It is the derivative of that timescale with respect to independently controlled variables.

3 Required Platform

A suitable platform must be mesoscopic enough for Penrose OR estimates to be meaningful and instrumented enough for BLQC variables to be exposed. Candidate classes include optomechanical, levitated-mass, cold-atom, interferometric, and QGEM-style pathfinder systems. The platform must preserve a usable visibility signal while also exposing the reference-tracking channel as an experimental variable.

Required capabilities:

- Create or probe a mesoscopic superposition or visibility signal with a measurable loss timescale.
- Vary mass, spatial separation, or mass distribution over a range large enough to change the Penrose OR estimate.
- Identify the physical basis-reference variable $\theta(t)$ used to define the measurement.

- Estimate or impose the reference instability/entropy-rate proxy h_{KS}.
- Vary useful basis-tracking capacity C_{eff} without changing mass geometry.
- Keep temperature, readout SNR, pulse/actuator behavior, sequence duration, and environmental coupling under monitored control.
- Preserve high-resolution reference logs whenever possible, so observer-relative reference loss can be separated from irreversible physical decoherence.

Exclusion criteria:

- The measurement basis is treated only as an external setting and cannot be monitored as a physical reference.
- Capacity variation changes temperature, readout backaction, or sequence duration in an uncontrolled way.
- Mass-geometry variation also changes the reference-tracking channel in a way that cannot be measured or modeled.
- The visibility-loss timescale is dominated by ordinary environmental decoherence with no usable dynamic range for either OR or BLQC variables.

4 Operational Variables

4.1 Mass-Geometry Variables

The Penrose side of the experiment requires independently specified mass-geometry variables:

- m: effective mass participating in the superposition or interferometric path distinction.
- s: spatial separation or equivalent branch-distinguishability scale.
- Geometry: shape and mass distribution relevant to E_G.

These variables must be changed while holding C_{eff}, h_{KS}, temperature, readout SNR, and sequence duration fixed or explicitly modeled.

4.2 Effective Basis-Tracking Capacity

The BLQC side requires a useful tracking-capacity variable:

$$C_{\text{eff}} = r\, b\, f, \tag{7}$$

where r is the useful update rate, b is the useful bits per update constraining the reference, and f is the fraction of updates that survive loss, rejection, latency, filtering, and estimator overhead.

C_{eff} is not raw controller power, raw ADC bandwidth, or a Landauer upper bound. It is the information rate by which the actual basis reference is constrained in the experiment.

Acceptable ways to vary C_{eff} include:

- changing accepted reference-update rate;
- changing useful bit depth;
- imposing calibrated packet/dropout schedules;
- changing estimator bandwidth or model order;
- changing filtering while preserving final readout SNR.

Artificial delay may be used only with latency-matched controls, because extra waiting time can produce ordinary coherence loss.

4.3 Reference Instability

The reference instability variable is h_{KS} or a calibrated proxy, such as a Lyapunov rate or prediction-error growth rate of the relevant basis-reference dynamics. It must be estimated from the same apparatus used in the Penrose-overlap test.

Acceptable estimation methods include:

- prediction-error growth from logged controller/plant states;
- Lyapunov exponent estimation for a fitted reference-dynamics model;
- calibrated injected reference instability on the target apparatus, with the injection path included in the platform model.

5 Experimental Design

The experiment should be run as a crossed or partially crossed design over mass-geometry and BLQC variables.

5.1 Baseline

For each platform, establish a baseline visibility curve $V(t)$ under stable reference tracking, stable temperature, stable readout SNR, and fixed mass geometry. The baseline must have enough visibility and dynamic range to identify a breakdown threshold V_*.

5.2 Capacity Sweep at Fixed Geometry

At fixed mass, separation, temperature, readout SNR, pulse/actuator behavior, sequence duration, and estimated h_{KS}, vary C_{eff} across a pre-registered range. Extract t_{break} for each condition.

BLQC predicts:

$$\frac{\partial t_{\mathrm{break}}}{\partial C_{\mathrm{eff}}} > 0 \quad (\kappa > 0). \tag{8}$$

Penrose OR predicts no leading dependence on C_{eff} when mass geometry and ordinary confounds are fixed.

5.3 Reference-Instability Sweep at Fixed Geometry

At fixed mass, separation, temperature, readout SNR, pulse/actuator behavior, sequence duration, and C_{eff}, vary h_{KS} or its calibrated proxy.

BLQC predicts:

$$\frac{\partial t_{\text{break}}}{\partial h_{\text{KS}}} < 0 \quad (\kappa > 0). \tag{9}$$

Penrose OR predicts no leading dependence on reference instability when mass geometry and ordinary confounds are fixed.

5.4 Mass-Geometry Sweep at Fixed Tracking Variables

At fixed C_{eff}, h_{KS}, temperature, readout SNR, pulse/actuator behavior, and sequence duration, vary mass, separation, or geometry.

Penrose OR predicts a geometry-dependent shift in τ_{OR}. BLQC predicts no leading shift unless the geometry change also alters C_{eff} or h_{KS}.

5.5 Randomization and Replication

Run order should be randomized across capacity, instability, and geometry settings. Each condition must include enough repetitions to estimate visibility with the pre-registered precision target. Replication should include at least one repeated condition after the full parameter sweep to detect slow drift.

6 Confound Controls

Thermal control. Temperature must be monitored at the mixing chamber and, where possible, through chip/platform proxies such as frequency drift, baseline coherence, or mechanical mode behavior. Capacity sweeps must not be accepted if they introduce uncontrolled heating.

Readout control. Readout SNR, detection efficiency, and readout-induced backaction must be monitored and included as nuisance variables. A capacity effect that tracks readout degradation is not evidence for BLQC.

Latency and wait-time control. Sequence duration and idle time must be matched across capacity conditions. If lower capacity merely adds waiting time, ordinary coherence loss explains the result.

Pulse and actuator control. Pulse amplitude, phase, actuator response, and plant diagnostics must remain within pre-registered tolerances. A capacity effect that tracks actuator distortion is confounded.

Offline reference logs. Where technically possible, the realized reference should be logged at higher resolution than the online tracker receives. Retrospective recovery of visibility classifies the effect as observer-relative reference loss rather than irreversible physical decoherence.

7 Statistical Analysis

7.1 Primary Observable

The primary observable is the breakdown time t_{break}, defined by a pre-registered visibility threshold:

$$V(t_{\text{break}}) = V_*. \tag{10}$$

Secondary observables include fitted decay-rate parameters, recovered visibility after offline reference correction, and model residuals across the parameter grid.

7.2 Models

Fit at least the following model classes:

BLQC model:

$$t_{\text{break}} = \frac{A}{h_{\text{KS}} - C_{\text{eff}} \ln 2} + B, \tag{11}$$

or the threshold-derived logarithmic form when σ_0 is estimated.

Penrose OR model:

$$t_{\text{break}} = A\,\tau_{\text{OR}}(m, s, \text{geometry}) + B. \tag{12}$$

Combined-rate model:

$$\frac{1}{t_{\text{break}}} = \alpha\,\frac{1}{\tau_{\text{OR}}} + \beta\,\kappa + \gamma, \tag{13}$$

allowing both mechanisms or mechanism-like rates to contribute.

Nuisance models: standard exponential, Gaussian, stretched-exponential, thermal/readout, latency, and actuator-response models.

7.3 Decision Rules

Support for BLQC in the Penrose-overlap regime requires all of the following:

- At fixed mass geometry and fixed ordinary confounds, t_{break} increases with C_{eff}.
- At fixed mass geometry and fixed ordinary confounds, t_{break} decreases with h_{KS}.
- Breakdown times collapse better against κ or $\rho = C_{\text{eff}} \ln 2/h_{\text{KS}}$ than against raw power, temperature, readout SNR, elapsed time, or actuator diagnostics.
- The capacity/instability effect is not fully explained by latency-matched ordinary coherence loss or offline-recoverable reference bookkeeping alone.

Support for Penrose OR or another mass-geometry mechanism requires:

- t_{break} follows mass/separation/geometry according to the OR estimate or another specified geometry-dependent model.
- t_{break} is independent of C_{eff} and h_{KS} within the experiment's sensitivity after ordinary confounds are controlled.

A combined result is possible. If both mass geometry and κ improve prediction, the result should be modeled as overlapping rates rather than assigned to either mechanism by inspection.

8 Falsification Criteria

BLQC is weakened or falsified in the tested regime if:

1. C_{eff} variation at fixed geometry and fixed confounds produces no measurable change in t_{break} under adequate sensitivity.
2. h_{KS} variation at fixed geometry and fixed confounds produces no measurable change in t_{break} under adequate sensitivity.
3. Apparent capacity dependence is fully explained by temperature, readout SNR, latency, pulse distortion, actuator nonlinearity, or post-selection.
4. Mass-geometry variables explain the data and κ adds no predictive value.

Penrose OR is weakened in this setup if:

1. mass/separation variation fails to move the loss timescale under adequate sensitivity;
2. C_{eff} or h_{KS} moves the timescale at fixed mass geometry in a way not explained by standard experimental confounds.

9 Minimum Reporting Requirements

Any report of the experiment should include:

- platform description and mesoscopic mass/separation estimates;
- Penrose OR timescale estimate and uncertainty;
- operational definition of C_{eff};
- operational definition or estimate of h_{KS};
- full thermal/readout/latency/pulse/actuator diagnostics;
- visibility curves for all parameter conditions;
- model-comparison statistics for BLQC, Penrose OR, combined-rate, and nuisance models;
- offline reference-log recovery analysis where available;
- pre-registered exclusion and confound criteria.

10 Conclusion

The Penrose-overlap experiment is the clean test of BLQC. It asks whether a mesoscopic visibility-loss timescale that could otherwise be attributed to gravitational objective reduction instead moves with finite-rate basis-reference tracking. If the timescale follows mass geometry and ignores C_{eff} and h_{KS}, Penrose OR or another geometry-dependent mechanism remains the better explanation. If the timescale follows $\kappa = h_{\text{KS}} - C_{\text{eff}} \ln 2$ at fixed mass geometry and after ordinary confounds are controlled, BLQC becomes a serious alternative or companion mechanism in the mesoscopic regime.