The Quantum Consensus Principle

A Thermodynamic Information Principle
for Quantum Measurement

Emergent Collapse from Large-Deviation Consensus Dynamics
in Open Quantum Systems

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March 2026

Abstract

Standard formulations of quantum measurement do not by themselves provide a universally accepted dynamical account of single-outcome selection. Within standard open-system quantum mechanics, the Quantum Consensus Principle (QCP) proposes a unified framework connecting microscopic detector dynamics, operational outcome statistics, and apparatus dependence.

Starting from a microscopic Hamiltonian description of system, apparatus, and environment dynamics, we derive a deformed positive operator-valued measure (POVM)

$$E_i = \sum_{j=1}^{d} S_{ij}\,\Pi_j, \quad S_{ij} \geq 0, \quad \sum_{i=1}^{d} S_{ij} = 1 \;\; \forall\, j, \tag{1}$$

whose weights depend on two canonical functionals of the apparatus response: the redundancy rate $\tilde{R}_i$ and the noise susceptibility χ_i. These quantities, defined in the Bogoliubov–Kubo–Mori (BKM) information geometry of the apparatus, are tied to microscopic Hamiltonian parameters via Green–Kubo transport coefficients $a(T, \eta, J)$ and $b(T, \eta, J)$.

Within the admissible class specified in the companion Supplement [companion Supplement]—causal CPTP dynamics on process-tensor path space, data-processing inequality (DPI) monotonicity, exact concatenation additivity, convexity/lower semicontinuity, and the stated KMS/regularity assumptions—the effective selection functional is unique up to affine gauge and, after calibration of the canonical sufficient statistics, takes the linear form $\Phi_i = a\,\tilde{R}_i + b_i\,\chi_i$. Competing nonlinear selectors are excluded within that explicit admissible class.

We establish that the conditioned system state forms a Hellinger contractive supermartingale, converging almost surely (i.e. with probability one) to a unique pointer state Π_{i^*}. Outcome probabilities follow from a path-space large-deviation principle, reproducing Born's rule in the apparatus-neutral limit and predicting measurable deviations for biased apparatuses. QCP yields a non-monotonic collapse timescale $\tau_{\mathrm{coll}}(\kappa)$ with a unique optimal measurement strength $\kappa_{\mathrm{opt}} = a/b$. These results identify quantum measurement as a thermodynamic consensus phenomenon, deriving collapse, outcome statistics, and apparatus dependence directly from Hamiltonian physics without modifying quantum mechanics.

Scope. The present main paper states the physical architecture of QCP and its front-end consequences in the Markovian pointer-preserving regime. The full admissibility, uniqueness, calibration, process-tensor extension, and counterexample-exclusion proofs are carried by the companion Supplement [companion Supplement] and notes [companion Born addendum; Necessity note]. The strongest claims are conditional on those standing assumptions and calibration conditions, rather than unrestricted statements about arbitrary detector models.

Contents

1 Introduction

Quantum measurement presents an unresolved structural gap: the unitary Liouvillian dynamics of quantum systems does not produce single outcomes, yet experiments do. Projection postulates [1, 2, 3] formalize collapse without mechanism; Everettian branches [4] preserve unitarity at the cost of ontic multiplicity. Objective collapse theories [5, 6, 7] modify the Schrödinger equation, and Bohmian mechanics [8] introduces hidden configuration-space trajectories. None explain how real detectors amplify microscopic information into macroscopic consensus. Open quantum systems theory [9, 10, 11, 12] and decoherence/einselection approaches [13] provide precise dynamical tools, but no existing framework derives the emergence of a unique pointer state, the Born rule, and the apparatus dependence of measurement statistics from a single principle.

Here we introduce the *Quantum Consensus Principle* (QCP): a universal information-theoretic mechanism by which measurement outcomes arise from large-deviation consensus selection in macroscopic detectors. QCP produces a mathematically rigorous collapse, quantitative timescales, auditability from microscopic Hamiltonians, and experimentally accessible deviations from Born statistics.

Detailed derivations and mathematical proofs are provided in the companion Supplement [companion Supplement]. A separate companion note [companion Necessity note] provides the complementary necessity statement: under explicit bare recorded unitary hypotheses, deterministic state-only one-world outcome selection is excluded on the reachable recorded state space.

2 Microscopic Model and Conditional Dynamics

2.1 Total Hamiltonian

Consider a measured system S, a macroscopic apparatus A, and a thermal environment E governed by the total Hamiltonian

$$H = H_S + H_A + H_E + H_{\text{int}}. \tag{2}$$

Definition 2.1 (Pointer projectors)**.** The pointer projectors $\{\Pi_i\}_{i=1}^d \subset \mathcal{B}(\mathcal{H}_S)$ form an orthogonal projection-valued measure (PVM) on the system Hilbert space $\mathcal{H}_S$:

$$\Pi_i \Pi_j = \delta_{ij}\Pi_i, \qquad \Pi_i = \Pi_i^\dagger, \qquad \sum_{i=1}^d \Pi_i = \mathbf{1}_S. \tag{3}$$

Definition 2.2 (Positive operator-valued measure (POVM))**.** A POVM on $\mathcal{H}_S$ is a set $\{E_i\}_{i=1}^d$ of positive semidefinite operators satisfying $E_i \geq 0$ and $\sum_{i=1}^d E_i = \mathbf{1}_S$. The probability of outcome i for a system in state ρ is $P(i|\rho) = \text{Tr}(E_i \rho)$.

The interaction term has the pointer-selective coupling form

$$H_{\text{int}} = \sum_{j=1}^d \Pi_j \otimes B_j, \tag{4}$$

where $B_j \in \mathcal{B}(\mathcal{H}_E)$ are bath operators satisfying KMS detailed-balance relations. Each channel j couples the pointer sector Π_j to its own bath operator B_j.

2.2 Lindblad generator

Under the standard weak-coupling, rotating-wave, and coarse-graining approximations (collectively the Born–Markov–Secular approximation [9, 14, 17]), the conditional dynamics of the reduced system state $\rho_t := \mathrm{Tr}_E(\rho_{\mathrm{tot},t})$ is governed by the stochastic master equation

$$d\rho_t = \mathcal{L}(\rho_t)\,dt + \sum_{i=1}^{d}\left(\frac{\Pi_i\rho_t\Pi_i}{\mathrm{Tr}(\Pi_i\rho_t)} - \rho_t\right)\big(dN_i(t) - \lambda_i(\rho_t)\,dt\big), \tag{5}$$

with Lindblad generator

$$\mathcal{L}(\rho) = -i[H_{\mathrm{eff}},\rho] + \sum_{i=1}^{d}\Big(L_i\,\rho\,L_i^\dagger - \tfrac{1}{2}\{L_i^\dagger L_i,\rho\}\Big), \tag{6}$$

and jump operators

$$L_i = \sqrt{\kappa_i}\,\Pi_i, \qquad \kappa_i = 2\pi\,\|A_i\|^2\,S_E(\omega_i) > 0. \tag{7}$$

Here $S_E(\omega)$ is the bath spectral density, A_i are the coupling operators entering the interaction Hamiltonian, and $\{dN_i(t)\}$ are Poisson increments with intensities $\lambda_i(\rho) = \kappa_i\,\mathrm{Tr}(\Pi_i\rho)$.

Remark 2.3 (Coupling operators). The Golden-Rule rates (7) involve the coupling operators A_i that appear in the Supplement's factored interaction form $H_{\mathrm{int}} = \sum_j \Pi_j \otimes A_j \otimes B$, where B is a collective bath operator. Identifying $B_j := A_j \otimes B$ in the appropriate contraction recovers the channel-specific form (4) used here, with $\kappa_i = 2\pi\|A_i\|^2 S_E(\omega_i)$.

Assumption 2.4 (QND / Pointer invariance)**.** The effective Hamiltonian $H_{\mathrm{eff}} = H_S + H_{\mathrm{LS}}$ (where H_{LS} is the Lamb shift) commutes with every pointer projector:

$$[H_{\mathrm{eff}},\Pi_i] = 0 \qquad \text{for all } i = 1,\ldots,d. \tag{8}$$

This quantum non-demolition (QND) condition ensures that the pointer basis is preserved under the coherent part of the dynamics. The jump rates κ_i follow directly from Fermi's Golden Rule and the bath spectral density $S_E(\omega)$; upward/downward rates for non-QND couplings obey KMS relations [9]. QCP uses no phenomenological parameters: all apparatus asymmetries enter through κ_i and through correlation functions defining the canonical scores below.

Standing assumptions. The following assumptions, inherited from the companion Supplement, are in force throughout this paper:

(A1) Valid Lindblad dynamics.
The reduced system state $\rho_t \in \mathcal{S}(\mathcal{H}_S)$ evolves via (6) with jump operators (7).

(A2) Pointer invariance / QND.
$[H_{\mathrm{eff}},\Pi_i] = 0$ for all i (Assumption 2.4); equivalently $[H_S,\Pi_i] = 0$, since $[H_{\mathrm{LS}},\Pi_i] = 0$ under the Secular approximation.

(A3) Dephasing dominance.
Off-diagonal elements of ρ in the pointer basis decay exponentially under the dynamics, guaranteeing classicalization of trajectories.

(A4) Identifiability.
The Kullback–Leibler divergence rate between trajectory statistics generated by any two distinct pointer states $\Pi_i \neq \Pi_j$ is strictly positive.

In addition, the bath assumptions (BKM/KMS) and the regularity assumption (A*) of the companion Supplement remain in force.

3 Canonical Scores: Redundancy and Susceptibility

Macroscopic detectors amplify microscopic alternatives via large networks of degrees of freedom. For each output channel i, QCP defines two canonical scores in terms of current operators on the apparatus Hilbert space. The *information current* $\mathcal{I}_i$ measures the rate at which the apparatus subsystem coupled to channel i produces distinguishable records; concretely, it is the operator whose BKM norm gives the mutual-information production rate between pointer sector i and the environment fragment. The *noise current* $\mathcal{B}_i$ measures the rate at which thermal fluctuations and entanglement-induced noise degrade the recorded information in channel i.

Definition 3.1 (Redundancy rate)**.** The redundancy rate $\tilde{R}_i$ is the asymptotic rate at which stable, distinguishable information about outcome i is produced in the apparatus:

$$\tilde{R}_i = \langle \mathcal{I}_i,\, \mathcal{I}_i \rangle_{\mathrm{BKM}}, \tag{9}$$

where $\mathcal{I}_i$ is the information-current operator and $\langle \cdot, \cdot \rangle_{\mathrm{BKM}}$ denotes the Bogoliubov–Kubo–Mori (BKM) inner product [15] on the apparatus state space.

Definition 3.2 (Noise susceptibility)**.** The noise susceptibility χ_i is the sensitivity of the apparatus record to thermal and entanglement-induced noise:

$$\chi_i = \langle \mathcal{B}_i,\, \mathcal{B}_i \rangle_{\mathrm{BKM}}, \tag{10}$$

where $\mathcal{B}_i$ is the noise-current operator.

Definition 3.3 (Green–Kubo coefficients)**.** The transport coefficients $a(T, \eta, J)$ and $b(T, \eta, J)$ entering the QCP potential are given by linear-response integrals [22]:

$$a = \int_0^\infty \langle \mathcal{I}_i(t)\, \mathcal{I}_i(0) \rangle_{\rho_E}\, dt, \qquad b = \int_0^\infty \langle \mathcal{B}_i(t)\, \mathcal{B}_i(0) \rangle_{\rho_E}\, dt, \tag{11}$$

where $\langle \cdot \rangle_{\rho_E}$ denotes the expectation with respect to the KMS equilibrium state of the bath at inverse temperature β. These link Φ_i directly to the microscopic Hamiltonian. The scores $(\tilde{R}_i, \chi_i)$ are static information-geometric quantities, while a, b quantify dynamical transport.

Remark 3.4 (Notation convention). We use the standard Lindblad normalization $L_i = \sqrt{\kappa_i}\, \Pi_i$, where κ_i are Golden-Rule jump rates. For channel-resolved outcome competition we write $\Phi_i = a\tilde{R}_i + b_i \chi_i$. In symmetric or one-parameter calibration scans we use the reduced notation $\Phi_{\mathrm{scan}}(\kappa) := b\, \chi(\kappa) - a\, \tilde{R}(\kappa)$ and define the scalar scan functional as a coupling-tuning functional. This is *not* a redefinition of the channel selector Φ_i; the sign inversion reflects the cost-minus-gain interpretation appropriate for locating the minimum of the scan [companion Supplement, Notation convention, p. S-3].

4 The Quantum Consensus Potential

Theorem 4.1 (Admissible linear selector; main-paper form)**.** *Within the explicit admissible class defined in the companion Supplement* [companion Supplement]—*causal CPTP/process-tensor dynamics, DPI monotonicity, exact concatenation additivity, convexity/lower semicontinuity, and the stated support/KMS regularity assumptions—the*

QCP selection functional is unique up to affine gauge. After identification of the two canonical sufficient statistics $\tilde{R}_i$ and χ_i, this yields the calibrated linear form

$$\Phi_i = a\,\tilde{R}_i + b_i\,\chi_i. \tag{12}$$

The stronger path-space uniqueness and no-competing-divergence statements are proved in the Supplement [companion Supplement, Theorem 10.1, Corollary 10.2]. *Competing nonlinear selectors are excluded within the above admissible class; outside that class, no such claim is made.*

Remark 4.2 (Non-monotonic collapse time). When scanning over measurement strength κ, the effective scan potential $\Phi_{\mathrm{scan}}(\kappa) = b\,\chi(\kappa) - a\,\tilde{R}(\kappa)$ has a U-shaped profile with a unique minimum at

$$\kappa_{\mathrm{opt}} = \frac{a}{b}. \tag{13}$$

Within the calibrated scan family considered here, this structure underlies a non-monotonic collapse time $\tau_{\mathrm{coll}}(\kappa) \sim 1/\gamma_{\min}(\kappa)$. This prediction is absent from all standard models (Copenhagen, Many-Worlds, Bohm, GRW). See [companion Supplement, Section 9.2] for the detailed derivation.

5 Large-Deviation Derivation of Outcome Probabilities

Let ρ_t denote the conditional state trajectory. Using a Doob h-transform of the path measure [18] (see [companion Supplement, Section 4] for the full construction), we establish the trajectory-level large-deviation principle [16]

$$\mathbb{P}(\rho_T \to \Pi_i) \asymp \exp\left[-T\,\Phi_i\right], \tag{14}$$

where $\asymp$ denotes logarithmic equivalence in the sense of large-deviation theory [16]:

$$\lim_{T\to\infty} \frac{1}{T} \log \mathbb{P}(\rho_T \to \Pi_i) = -\Phi_i.$$

Normalization defines a column-stochastic response matrix S and the QCP POVM:

$$E_i := \sum_{j=1}^{d} S_{ij}\,\Pi_j, \quad S_{ij} \geq 0, \quad \sum_{i=1}^{d} S_{ij} = 1\ \ \forall\, j, \quad P(i|\rho) = \mathrm{Tr}(E_i\rho). \tag{15}$$

5.1 Operational probability law and neutral limit

In QCP, outcome probabilities are defined operationally as asymptotic frequencies of stochastic trajectories (see [companion Born addendum, Definition 3.1]). They are *not* postulated at the level of measurement outcomes. For a general calibrated instrument, the exact output law is

$$P(I^* = i) = \mathrm{Tr}(E_i\rho_0), \qquad E_i = \sum_j S_{ij}\,\Pi_j, \tag{16}$$

with S column-stochastic.

Definition 5.1 (Neutral apparatus)**.** The apparatus is *neutral* if $S = I$ (the identity matrix), equivalently $E_i = \Pi_i$ for all i. By Corollary 2.6 of the Supplement [companion Supplement], this is the limit in which $\Phi_i = \text{const}$ across channels.

In the neutral case, the posterior process $M_i(t) := \text{Tr}(\Pi_i \rho_t)$ is a bounded martingale ([companion Born addendum, Theorem 4.1]), and together with almost-sure collapse to pointer sectors this yields

$$P(I^* = i) = \text{Tr}(\Pi_i \rho_0). \tag{17}$$

Thus the Born rule is the exact trajectory-frequency law of the neutral instrument, not an independent probability postulate [companion Born addendum]. Away from neutrality, first-order deviations are stated only for smooth response-matrix families $S(\varepsilon)$; see [companion Born addendum, Theorem 6.3].

Remark 5.2 (Born is not presupposed). Corollary 6.5 of the Born addendum [companion Born addendum] establishes: $P(I^* = i) = \text{Tr}(\Pi_i \rho_0)$ for all states and all i if and only if $S = I$. Since QCP predicts apparatus-dependent deviations whenever $S \neq I$, it follows by *modus tollens* that Born is not an axiom of QCP but a derived fixed-point property of the neutral instrument.

6 Emergent Collapse Dynamics

The stochastic process $\{\rho_t\}$ is a supermartingale under the natural filtration generated by measurement events. We construct a Lyapunov functional from the squared Hellinger distance to the nearest pointer-state vertex:

Definition 6.1 (Hellinger-Lyapunov functional)**.** Let $p_k(\rho) := \text{Tr}(\Pi_k \rho)$ be the pointer probabilities and e_k the k-th standard basis vector. Define

$$\mathcal{V}(\rho) := \min_{k \in \{1,\dots,d\}} D_H^2\big(p(\rho), e_k\big) = 2\Big(1 - \max_k \sqrt{p_k(\rho)}\Big), \tag{18}$$

where $D_H^2(p, q) := \sum_i (\sqrt{p_i} - \sqrt{q_i})^2$ is the squared Hellinger distance [23]. The functional $\mathcal{V}$ is non-negative and equals zero if and only if ρ is a pointer state ($p = e_k$ for some k).

Theorem 6.2 (Consensus collapse)**.** *Under the standing assumptions* (A1)–(A4) [companion Supplement, Section 3]*, the conditioned state process admits a Hellinger-type Lyapunov functional and converges* almost surely *(i.e. with probability one, in the measure-theoretic sense of Doob's supermartingale convergence theorem* [25]*) to a pointer projector:*

$$\rho_t \longrightarrow \Pi_{i^*} \qquad \textit{almost surely}, \tag{19}$$

where i^* is a random index determined by the trajectory. The exponential contraction bound is

$$\mathbb{E}[\mathcal{V}(\rho_t)] \;\le\; e^{-\kappa_{\min} t}\, \mathcal{V}(\rho_0), \qquad \kappa_{\min} := \min_i \kappa_i > 0. \tag{20}$$

The contraction rate $\bar{\kappa}(p) := \sum_i \kappa_i\, p_i(\rho) \ge \kappa_{\min}$ is a monotone decreasing function of the potential: smaller Φ_i implies larger spectral gap and faster collapse.

Proof sketch (full proof: [companion Supplement, Theorem 3.1, Lemma A.3]). The QND condition (8) ensures the Hamiltonian part of the generator preserves pointer probabilities. Each quantum jump into channel i sends the post-jump state to $\sigma_i = \Pi_i \rho \Pi_i / \text{Tr}(\Pi_i \rho)$, for which $\mathcal{V}(\sigma_i) = 0$ exactly. Therefore the dissipative generator satisfies $\mathcal{G}\mathcal{V}(\rho) = -\bar{\kappa}(p)\,\mathcal{V}(\rho) \le -\kappa_{\min}\mathcal{V}(\rho)$. Since $\mathcal{V} \ge 0$, Doob's supermartingale convergence theorem gives $\mathcal{V}(\rho_t) \to 0$ a.s., hence $\rho_t \to \Pi_{i^*}$. □

Remark 6.3 (Non-monotonic collapse time). Because $\Phi_{\mathrm{scan}}(\kappa)$ is U-shaped, $\gamma(\kappa)$ is $\cap$-shaped, and $\tau_{\mathrm{coll}}(\kappa) \sim 1/\gamma_{\min}(\kappa)$ has a unique minimum at $\kappa_{\mathrm{opt}} = a/b$. For weak coupling ($\kappa \ll \kappa_{\mathrm{opt}}$), the process is information-limited (insufficient redundancy amplification). For strong coupling ($\kappa \gg \kappa_{\mathrm{opt}}$), it becomes noise-limited (excessive thermal backaction). The optimal point κ_{opt} identifies the thermodynamically optimal consensus rate [companion Supplement, Section 9.2].

7 Non-Markovian Robustness

The Markovian pointer-preserving regime serves as the reference front-end model. The companion Supplement formulates the corresponding path-space uniqueness, POVM validity, and no-signalling statements on process-tensor path space [19, 20] under explicit causality, DPI, additivity, support, and KMS/regularity assumptions [companion Supplement, Section 2.12]; cf. [21] for the process-tensor framework.

Accordingly, robustness beyond Markov/QND is claimed only in that conditional sense. The formal derivation of the process-tensor formulation and the proof of invariance of the RSK-linear potential under non-Markovian dynamics are given in [companion Supplement, Section 2.12].

8 Predictions and Falsifiability

QCP makes several experimentally accessible predictions.

8.1 Non-monotonic collapse rate

In continuous-measurement platforms (superconducting qubits [29], NV centres, trapped ions), varying the measurement strength κ must yield a U-shaped collapse time $\tau_{\mathrm{coll}}(\kappa)$ with a device-specific optimum at $\kappa_{\mathrm{opt}} = a/b$ (13).

8.2 Born deviations for biased apparatus

Definition 8.1 (Apparatus bias parameter)**.** Let $\beta \mapsto S(\beta)$ be a C^1 family of column-stochastic response matrices with $S(0) = I$. The scalar parameter $\beta \geq 0$ quantifies the deviation of the apparatus from neutrality; its value is determined by the microscopic apparatus data (T, η, J) through the calibrated map $(T, \eta, J) \mapsto S$ of the companion Supplement. The neutral limit corresponds to $\beta = 0$, where Born statistics are recovered exactly.

For asymmetrically structured detectors with bias parameter $\beta > 0$,

$$D_{\mathrm{tr}}(P_{\mathrm{QCP}}, P_{\mathrm{Born}}) = O(\beta), \tag{21}$$

where D_{tr} denotes the trace distance between the QCP outcome distribution and the Born distribution. Modern POVM tomography [27, 28] can resolve such deviations.

8.3 Microscopic auditability

All parameters of QCP are operationally measurable:

- The microscopic coupling strengths κ_i can be determined from spectroscopy of the environmental response.
- The transport coefficients a and b are obtained from Green–Kubo integrals (11).
- The redundancy rates $\tilde{R}_i$ and noise susceptibilities χ_i can be extracted through partial monitoring of the environment.
- The effective measurement operators E_i are reconstructable via multi-strength quantum tomography [26, 27].

Together, these render QCP a fully falsifiable physical theory.

9 Comparison with Existing Frameworks

Framework	Outcome selection	Born rule	Distinctive predictions	Assumptions
Copenhagen	Postulated collapse	Axiom	None	Classical observer cut
Many-Worlds	None (all branches persist)	Derived (decision-theoretic)	None beyond standard QM	Ontology of branches
Bohmian mechanics	Deterministic pilot-wave	Reproduced	Nonlocal hidden variables	Additional particle ontology
GRW / CSL	Spontaneous localization	Modified	Heating, localization events	New fundamental constants
Quantum Darwinism [24]	Redundant environment encoding	Assumed	Spectrum-broadcast structure	Standard decoherence
QCP	**Thermodynamic attractor selection**	**Derived (martingale collapse)**	**Apparatus-dep. POVM deformation**	**Standard open QM dynamics**

Table 1: Comparison of quantum measurement frameworks. QCP is the only framework that (i) derives outcome selection from standard open-system dynamics, (ii) derives Born's rule as a neutral fixed point, and (iii) predicts apparatus-dependent deviations.

10 Discussion

QCP reconceives measurement as an information-driven nonequilibrium phase-selection process. Collapse is not an exception inserted into the formalism; it is the inevitable attractor of redundancy-amplifying dynamics. The Born rule becomes a statement of apparatus neutrality, not a primitive axiom. The theory offers:

- no new ontology,
- no hidden variables,
- no nonlinear Schrödinger corrections,
- no branching universes.

Instead, outcome selection results from thermodynamic consensus, governed by universal constraints on CPTP maps, DPI, and information geometry. The formalism unifies quantum measurement with statistical physics: macroscopic measurement devices act as large-deviation engines, computing the most stable macroscopic alternative.

11 Conclusion

We have presented the Quantum Consensus Principle (QCP), a first-principles framework that derives quantum measurement as an emergent thermodynamic phenomenon. Starting from microscopic Hamiltonian dynamics and extending through information-geometric and path-space large-deviation formalisms, QCP provides a unified and quantitatively predictive description of measurement.

In the Markovian pointer-preserving regime emphasized here, and under the standing assumptions carried by the companion materials [companion Supplement; Born addendum], QCP yields:

(i) an almost-sure collapse architecture (Theorem 6.2);
(ii) an apparatus-dependent POVM description (15);
(iii) a non-monotonic calibrated collapse-time prediction (Remark 6.3).

In the neutral instrument limit $S = I$, the Born law is recovered as the exact operational trajectory-frequency law (17) [companion Born addendum]; away from neutrality, calibrated response matrices generate controlled POVM-level deviations that are, in principle, experimentally testable.

By grounding outcome selection in the universal thermodynamics of information production, QCP transforms the measurement problem from an interpretational postulate into a derived physical process.

A separate companion note [companion Necessity note] supplies a narrower necessity statement: under bare recorded unitary dynamics, explicit record hypotheses, support faithfulness, and reachable relabelling covariance, no deterministic state-only single-outcome selector exists on the reachable recorded state space. This closes one direct state-only route within the stated formal setting, while the positive uniqueness of the admissible path-space selector remains the independent content of the companion Supplement [companion Supplement].

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