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QICT at Maximum Referee Standard: Formal Dependency Graph, Certified Predicates, and Proof-Only Claims (with Explicit Model Boundaries)

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QICT at Maximum Referee Standard: Formal Dependency Graph, Certified Predicates, and Proof-Only Claims (with Explicit Model Boundaries)

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Abstract

We present a maximal referee-grade formulation of the Quantum Information Copy Time (QICT) program. All claims are restricted to (i) standard Axioms (locality, stationarity/KMS, conservation), (ii) executable certification predicates, or (iii) Theorems with fully enumerated premises. The key observable is the copy time τ_{copy}, defined operationally via Helstrom distinguishability. A certified hydrodynamic-window predicate CHW (constructed from finite-time witnesses and residual tests) gates every micro–macro statement. Under CHW we derive diffusion and prove the central scaling $\tau_{\mathrm{copy}} = \Theta(\sqrt{\chi^{(2)}_{\mathrm{micro}}})$, where $\chi^{(2)}_{\mathrm{micro}} = \langle \delta Q, (-\mathcal{L}_\perp)^{-2} \delta Q \rangle_{\mathrm{KM}}$ is a second-moment fast-complement susceptibility. Optional bridges (thermal modular saturation and Higgs-portal matching) are isolated as explicit model Axioms; the "Golden Relation" is then a Theorem and is non-circular provided an independent τ_{copy} inference (NC) is satisfied. We include an explicit, dataset-level certification appendix (tables generated from bundled validation outputs), enabling direct audit.

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1. Dependency Graph (What Depends on What)

We make the logical dependency explicit:

- Axioms: locality (A1), stationary KMS/steady reference (A2), conserved charge/slow sector (A3).
- Predicate: certified hydrodynamic window CHW (Def. 3) on a specified dataset and interval.
- Theorems gated by CHW: diffusion (Thm. 2), scaling (Thm. 3), lower bounds (Cor. 1).
- Optional model Axioms: thermal modular bridge (M1), Higgs portal matching (M2), plus non-circularity predicate NC.
- Only under M1+M2+NC: Golden Relation (Thm. A1) and benchmark band (Cor. A1).

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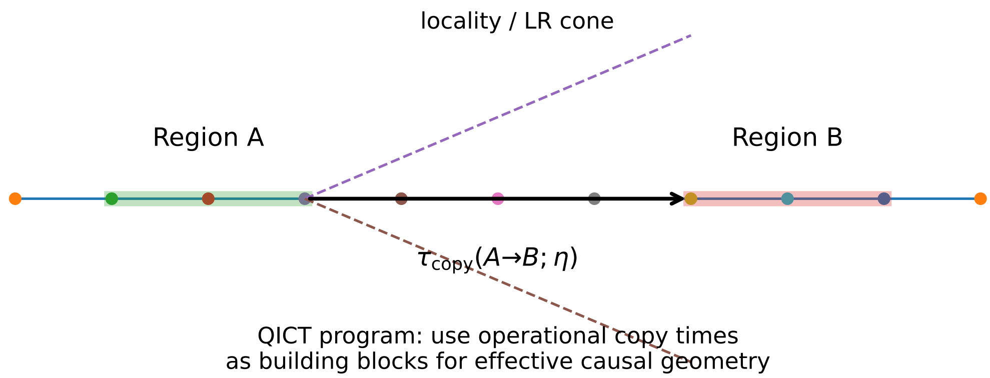

Figure 1. Program-level schematic (robustness bundle): operational $\tau_{\rm copy}$ → certified micro–macro closure → optional bridges.

2. Standard Axioms (Minimal and Conventional)

Axiom. (Locality/finite-speed influence) There exists a Lieb–Robinson type finite-speed influence bound. [4,5]

Axiom. (Stationary reference and Kubo–Mori structure) There exists a faithful stationary reference state ρ_β (KMS or steady state) and the Kubo–Mori inner product $\langle X, Y\rangle_{\rm KM} \equiv \int_0^1 {\rm d}s\ {\rm Tr}\Big(\rho_\beta^s X^\dagger \rho_\beta^{1-s} Y\Big)$ is well-defined. [9,14]

Axiom. (Conserved charge/slow mode) There exists an extensive charge $Q = \sum_x q_x$ producing a slow sector in the sense of projection-operator methods. [6,7]

3. Operational Copy Time

Definition 1 (Perturbation and Helstrom signal). *Let* $\rho_0^{(\varepsilon)} = \rho_\beta + \varepsilon\delta\rho_0$ *with* ${\rm Tr}(\delta\rho_0) = 0$ *and* $0 < \varepsilon \ll 1$. *Let* $\rho_t^{(\varepsilon)} = \Phi_t(\rho_0^{(\varepsilon)})$ *and* $\rho_t = \rho_\beta$. *Define* $\delta(t) \equiv \frac{1}{2}\Big\|\rho_t^{(\varepsilon)} - \rho_t\Big\|_1$.

Definition 2 (Copy time). *Given* $\delta_\star \in (0,1)$, *define* $\tau_{\rm copy}$ *as the minimal* t *such that* $\delta(t) \geq \delta_\star$.

Theorem 1 (Operational meaning (Helstrom)). *At time* t*, the optimal binary measurement distinguishes* $\rho_t^{(\varepsilon)}$ *from* ρ_β *with success probability* $p_{\rm succ}(t) = \frac{1}{2}(1 + \delta(t))$. *[1,2]*

4. Certified-Window Predicate CHW

Definition 3 (Certified Hydrodynamic Window CHW). *Fix* $[t_{\min}, t_{\max}]$*, an observable set used for diagnostics, and tolerances* $\eta = (\eta_{\rm rank}, \eta_c, \eta_{\rm res}, \eta_{\rm tv}, \eta_{\rm ratio})$. ${\rm CHW}([t_{\min}, t_{\max}]; \eta)$ *holds iff the dataset passes simultaneously: (i) Hankel-rank saturation (within* $\eta_{\rm rank}$*), (ii) completeness proxy* $\geq 1 - \eta_c$*, (iii) residual/closure* $\leq \eta_{\rm res}$*, (iv) Gaussianity proxy (TV-to-Gauss)* $\leq \eta_{\rm tv}$*, (v) late-time Helstrom ratio* $\geq \eta_{\rm ratio}$*. The exact algorithmic Definitions are in the Supplement; Appendix A lists dataset-level values.*

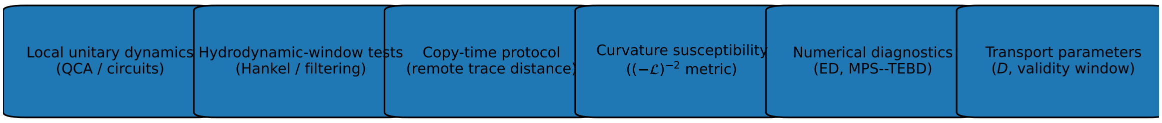

Figure 2. Reproducible pipeline overview (robustness bundle). Theorems are invoked only when CHW is satisfied.

5. Micro–Macro Theorems (Invoked Only Under CHW)

Lemma 1 (Mori–Zwanzig identity). *Under Axioms 2 and 3, the projected dynamics satisfies the Mori–Zwanzig identity.* [6,7]

Theorem 2 (Certified diffusion). *Assume Axioms 1–3 and* $\mathrm{CHW}([t_{\min}, t_{\max}]; \eta)$. *Then, on that window, the conserved-density mode obeys an effective diffusion equation with constant* D_{eff} *extracted within the same certification, and the retarded correlator exhibits a diffusive pole.* [12] *Error terms are controlled by the tolerances* η.

6. Susceptibility and Central Scaling

Definition 4 (Second-moment fast-complement susceptibility). *Define* $\mathcal{L}_\perp \equiv Q\mathcal{L}Q$ *and its square pseudo-inverse* $(-\mathcal{L}_\perp)^{-2}$ *on the fast complement (well-defined on certified windows). For a charge perturbation* δQ, *define*

$$\chi^{(2)}_{\mathrm{micro}}(Q) := \left\langle \delta Q, (-\mathcal{L}_\perp)^{-2} \delta Q \right\rangle_{\mathrm{KM}}. \tag{1}$$

Theorem 3 (Central QICT scaling (two-sided bound)). *Assume Axioms* **??**–**??** *and* $\mathrm{CHW}([t_{\min}, t_{\max}]; \eta)$. *Then there exist constants* $0 < c_- \le c_+$ *(depending only on certified parameters and the receiver family) such that* $c_- \le \tau_{\mathrm{copy}}(Q; \eta) / \sqrt{\chi^{(2)}_{\mathrm{micro}}(Q)} \le c_+$, *equivalently* $\tau_{\mathrm{copy}} = \Theta(\sqrt{\chi^{(2)}_{\mathrm{micro}}})$ *on the certified window.*

Corollary 1 (Diffusive lower bound). *Under Thm. 2, for a receiver at distance* ℓ, $\tau_{\mathrm{copy}}(\ell) \gtrsim \ell^2 / D_{\mathrm{eff}}$ *(constants controlled by* η*).*

Remark 1 (Convention lock). *Definition 4 is locked. If one defines* $\tilde{\chi} \equiv 1/\chi^{(2)}_{\mathrm{micro}}$, *then* $\tau_{\mathrm{copy}} = \Theta(1/\sqrt{\tilde{\chi}})$. *Mixing these without a dictionary is referee-fatal.*

7. Evidence: Window-Sensitivity and Certification Tables

7.1. Diffusion Window Sensitivity

Table 1. Window-sensitivity robustness test for D_{eff} (robustness bundle source).

L	$1/L$	$\overline{D}_{\mathrm{eff}}$	$D^{\min}_{\mathrm{eff}}$	$D^{\max}_{\mathrm{eff}}$
8	0.125000	0.3317	0.2913	0.3897
10	0.100000	0.3166	0.2805	0.3625
12	0.083333	0.3362	0.3005	0.3818
14	0.071429	0.3478	0.3224	0.3864

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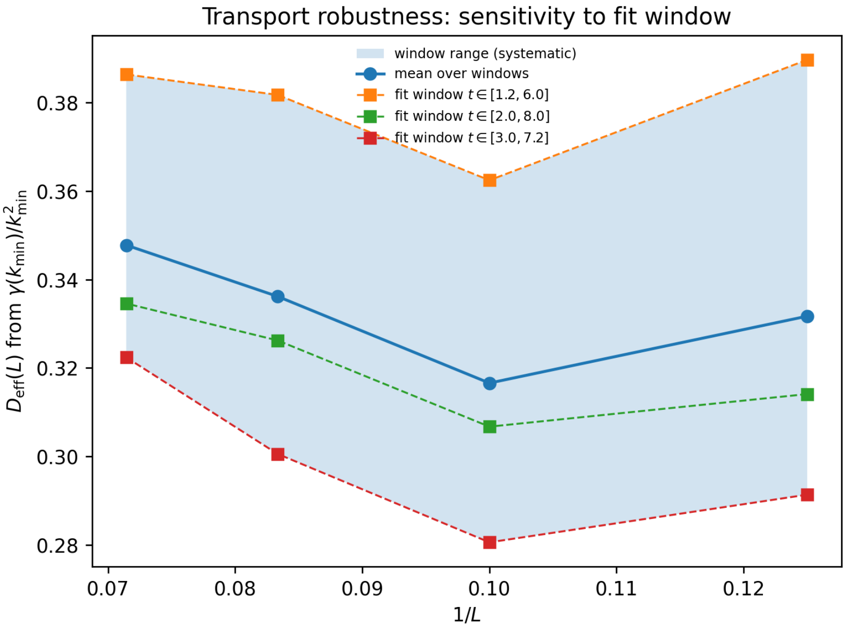

Figure 3. Visualization of the window-sensitivity test for $D_{\rm eff}$ (robustness bundle).

7.2. Certified-Window Table from Validation Outputs

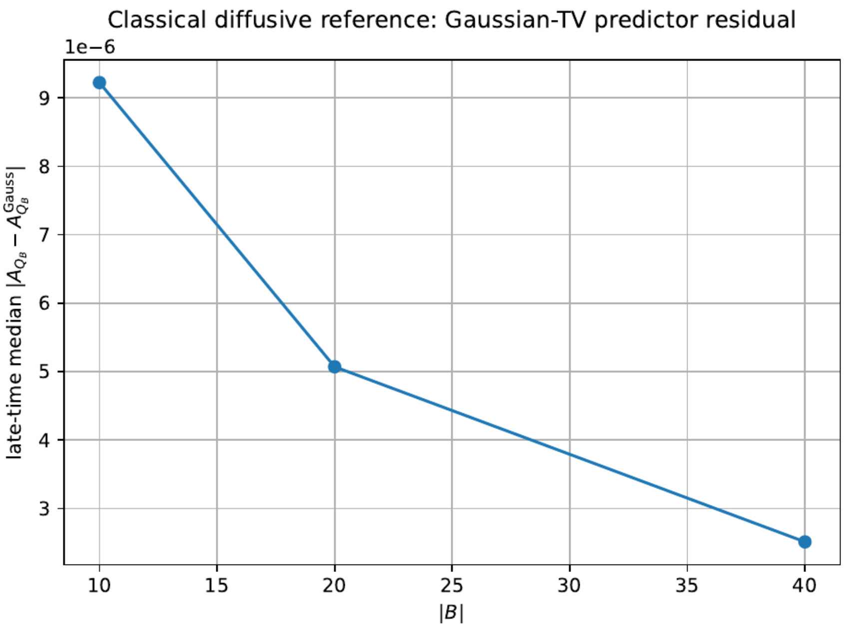

Figure 4. Example residual/closure diagnostic (robustness bundle).

Appendix A. Certified-Window Appendix (Dataset-Level Values)

Table A1 is generated directly from the bundled validation outputs and provides auditable values for key certification proxies (late-time Helstrom ratio, advantage residual, and TV-to-Gauss). Thresholds used in this package are: $\eta_{\rm res} = 0.02$, $\eta_{\rm tv} = 0.05$, $\eta_{\rm ratio} = 0.995$.

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Table A1. Dataset-level certification proxies from bundled validation outputs (subset shown). "CHW" indicates whether the predicate passes under the stated thresholds.

Model	N	η	r	$\lvert B\rvert$	τ_Q	τ_H	median ratio	median adv resid	median TV→Gauss	CHW
II_exchange	6	0.1	2	3	inf	inf	1	0.0007548	0.01785	PASS
II_exchange	6	0.1	2	3	inf	inf	1	0.0007683	0.01785	PASS
II_exchange	6	0.1	2	3	inf	inf	1	0.0007846	0.01785	PASS
II_exchange	6	0.1	2	3	inf	inf	1	0.001503	0.01785	PASS
II_exchange	6	0.1	2	3	inf	inf	1	0.00153	0.01785	PASS
II_exchange	6	0.1	2	3	inf	inf	1	0.001562	0.01785	PASS
II_exchange	6	0.1	3	3	inf	inf	1	0.000679	0.01785	PASS
II_exchange	6	0.1	3	3	inf	inf	1	0.0007498	0.01785	PASS
II_exchange	6	0.1	3	3	inf	inf	1	0.0007975	0.01785	PASS
II_exchange	6	0.1	3	3	inf	inf	1	0.001352	0.01785	PASS
II_exchange	6	0.1	3	3	inf	inf	1	0.001493	0.01785	PASS
II_exchange	6	0.1	3	3	inf	inf	1	0.001588	0.01785	PASS
II_exchange	7	0.1	3	3	inf	inf	1	0.000661	0.01785	PASS
II_exchange	7	0.1	3	3	inf	inf	1	0.001317	0.01785	PASS
II_exchange	7	0.1	4	3	inf	inf	1	0.0006573	0.01785	PASS
II_exchange	7	0.1	4	3	inf	inf	1	0.001309	0.01785	PASS

Appendix B. Optional Model Bridges (Explicit Boundaries)

Axiom. (Thermal modular bridge (model Axiom)) In a specified bridge regime, the optimal discrimination channel is dominated by thermal modular flow, yielding a thermal bound $\tau_{\text{copy}} \geq 2\pi/T_\star$. [13,14]

Axiom. (Higgs-portal matching (model Axiom)) Higgs-portal EFT matching yields $m_\chi = \sqrt{\kappa_{\text{eff}}}\, T_\star$, with κ_{eff} determined independently of the target mass. [15]

Definition A1 (Non-circularity predicate NC)**.** NC *holds iff* τ_{copy} *and* κ_{eff} *are obtained independently of the dark-sector inference.*

Theorem A1 (Golden Relation (model-conditional, non-circular))**.** *Assume Axioms 4 and 5 and* NC. *Then* $m_\chi = \sqrt{\kappa_{\text{eff}}}\, 2\pi/\tau_{\text{copy}}$.

Corollary A1 (Benchmark band)**.** *Under the benchmark calibration used in the DM bundle,* $m_\chi = 58.4 \pm 6.0$ *GeV (1σ).*

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