The Universal Embedding Principle: Quantum Probability, Bell Correlations, and the Cosmic Bell Test in the Selective Transient Field Framework

A consistency result: the retarded/advanced closure of the STF framework embeds quantum probability without contradiction, reproduces Bell correlations with no-signaling intact, sits on the untouched side of the Cosmic Bell test — and states precisely the theorem that would turn the embedding into a derivation

Z. Paz · ORCID 0009-0003-1690-3669 V1.1 2026

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Abstract

The Cosmic Bell experiments (Handsteiner et al. 2017; Rauch et al. 2018) determined Bell-test measurement settings from the light of Milky Way stars and then of high-redshift quasars, pushing back to at least 7.8 Gyr the most recent time at which any local-realist mechanism could have exploited the freedom-of-choice loophole, and excluding such mechanisms from 96% of the spacetime volume of the past light cone of the experiment. This paper establishes the relationship between those results and the STF framework, and does so with an exactness that the framework's discipline demands. Three results are stated. **First**, a jurisdictional result: the STF corpus makes no hidden-variable claim about quantum correlations, and its retrocausal channel is a field-theoretic retarded/advanced structure closing on the complexified null cone; the Cosmic Bell test targets past-common-cause correlations between settings and hidden variables and is structurally blind to future-boundary structures, which retrocausal accounts have always occupied — so the test neither confirms nor threatens STF. **Second**, a consistency result: using only structure the framework already has — the Hopf/anti-Hopf conjugate sectors of Topological Closure V6.3 with $\int_{T^2_\gamma} \omega_R \wedge \omega_A = 4\pi^2$, an anti-linear real-structure map J exchanging them, and the universal/local time distinction proved in the Clock-Separation Theorem — one can define a two-clock transaction functional $D(k,\ell) = A_k \bar{A}_\ell \langle R_\ell | R_k \rangle$ that is Hermitian, positive semidefinite, normalized by universal closure (the $4\pi^2$ cancels exactly), interference-preserving before internal recording and Born-diagonal after it; inserting the unique SU(2)-invariant singlet amplitude $\varepsilon_{\alpha\beta}/\sqrt{2}$ reproduces $P(A,B|a,b) = \frac{1}{4}(1 - AB\, a\cdot b)$ with b-independent marginals, and the construction is proposed to extend kinematically to spin-$\frac{1}{2}$ and photon fields, which share the scalar's characteristic null cone (a proposal, not a proof: the required spin-frame bundle and outcome-fiber adjoint are open). **Third**, an honesty result: the Born rule is *inherited* here, not derived — sesquilinearity enters through the choice that J is anti-linear, motivated by the anti-Hopf conjugation but not forced by the torus. What is proved is that STF is Born-compatible and Bell-compatible: its two-clock architecture is a consistent interpretation in the transactional / consistent-histories family, in which universal time labels the closed two-branch (Schwinger–Keldysh) history and internal clocks generate local records. We name the **Universal Embedding Principle** — every post-activation process is embedded in the universe's closed causal history, but only locally closed systems generate an internal clock and their own advanced arc — show it to be an entailment of the framework's State-1/State-3 distinction, and use it to resolve why sub-threshold laboratories exhibit Bell violations without any local STF activation. We state precisely the theorem that would upgrade compatibility to derivation: the universal-to-local gluing map, $(1/4\pi^2)\int\langle r(C_\beta), r(C_\alpha)\rangle = \mathrm{Tr}(C_\alpha \rho_U C_\beta^\dagger)$ — including, as a necessary component, an outcome-fiber adjoint theorem forcing the appropriate anti-linear structure — which is not proved and is not assumed; and we show that the terminal boundary must be a thermodynamic macrocondition (a pure terminal microstate would impose Aharonov–Bergmann–Lebowitz postselection and depart from Born statistics), that topological closure cannot select one outcome among the histories it normalizes, and that "one real history" is therefore a priced commitment — a Single-Transaction Ontology — not a theorem.

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1. What the Cosmic Bell test established

Bell's inequality is derived from a conjunction of assumptions, and a violation tells one only that at least one fails. Bell's derivation rests on two assumptions about a hidden variable λ: *measurement independence*, $\rho(\lambda|a,b) = \rho(\lambda)$, and *factorizability* (local causality), $P(A,B|a,b,\lambda) = P(A|a,\lambda)P(B|b,\lambda)$. The freedom-of-choice loophole is the possibility that the first fails — that the hidden-variable distribution is correlated with the measurement settings, $\rho(\lambda|a,b) \neq \rho(\lambda)$. (The embedding adopted in this paper, §2, *preserves* the first relation and rejects the second, through an imported nonseparable quantum state; that is what Bell's theorem actually tests.) The Cosmic Bell program closes the *past-light-cone* route to that failure. In 2017 settings were drawn from Milky Way starlight, ensuring the setting-generating events lay outside the past light cone of everything that could have coordinated them within ~600 years; in 2018 settings were drawn from quasars whose light was emitted 7.78 and 12.21 Gyr ago, and a Bell violation of 9.3 standard deviations was observed under the fair-sampling and no-tampering assumptions. Any local-realist conspiracy would have had to begin operating — knowing when, where, and how the experiment would be done — at least 7.8 Gyr ago.

What this excludes must be stated with care, because the exclusion has a direction. There are two physically distinct ways to violate Statistical Independence. The first is superdeterminism: settings and hidden variables correlated through a common cause in their joint past. The second is retrocausality: a direct influence from the future settings to the past hidden variables, which treats the settings as exogenous in the ordinary way and locates some of their effects in the past. The Cosmic Bell test attacks the first mechanism only — its entire design is to place the settings' origin outside any coordinating past. It is structurally blind to the second, because a retrocausal channel does not route through the past light cone at all: it routes through the future boundary, which the quasar cannot reach and does not need to. Even the superdeterminism literature concedes that these experiments rule out only local common-past coordination.

2. Jurisdiction: what STF does and does not claim

An audit of the corpus establishes the first result at once. No STF paper makes a hidden-variable claim about quantum correlations, offers a mechanism for entanglement statistics, or takes a position on superdeterminism. The framework's retrocausal channel is a field-theoretic structure — retarded and advanced solutions of a scalar coupling to the rate of change of curvature, closing on the complexified null cone at astrophysical and biological scales — not a hidden-variable model of quantum measurement. The Cosmic Bell test therefore has no purchase on STF's core claims. **Status: established by inspection.**

Suppose, however, the framework were pressed toward the quantum scale. Its existing commitments place it, by prior construction, on the untouched side of the fault line:

- *Directional novelty* (One Bit of Destiny). The interior of a closed loop is independent of its future boundary, not of its past; dictation from the future is excluded, determinism from the past is left open. That is the retrocausal, not the superdeterministic, structure.
- *The one-bit lemma.* The advanced arc carries one integer — the closure certificate — because it is a homotopy-class invariant. This is stronger than "no classical signal": the object crossing the backward channel cannot encode a trajectory in principle. This makes STF's backward channel bandwidth-starved; it does not by itself prove no-signaling — even one bit can signal if its value or distribution is controllably setting-dependent. No-signaling in the construction below is *inherited*: it follows from the imported quantum state and trace-preserving local instruments, $p(A|a,b) = p(A|a)$, and has the same status as the Born rule — compatible, not independently derived.
- *Ancestry.* The corpus cites Wheeler–Feynman, Cramer, and Price — the retrocausal family that treats settings as free and lets their effects lie in the past — as its lineage.

The strongest attack ever mounted on Bell-loophole mechanisms is aimed at a mechanism the STF framework does not use, and it is built on the null-cone geometry STF is built on. That is a relationship, and a favorable one; it is not a confirmation, and this paper does not present it as one.

One choice must be made explicit here, because two distinct Bell reconciliations are in play and they are not the same. The first — described in §1 and occupied by the retrocausal hidden-variable literature — violates Statistical Independence through a future-boundary channel, $\rho(\lambda|a,b) \neq \rho(\lambda)$. The second — the one the construction of §4–§6 actually adopts — introduces *no* Bell hidden variable λ, *preserves* measurement independence, lets the settings enter only through local quantum instruments, and inherits Bell nonfactorizability from an imported nonseparable quantum state; Born probabilities and no-signaling are inherited with it. **This paper adopts the second path.** The retrocausal measurement-dependence route is discussed above only as the alternative that explains why the Cosmic Bell test has no jurisdiction over future-boundary structures; it is not the mechanism used here. Stated this way the relationship to the Cosmic Bell test is exceptionally clean: the test constrains common-past measurement dependence, while the adopted embedding violates Bell factorization through the entangled state and nothing else.

3. The Universal Embedding Principle

The framework's four-state ontology (General Theory §1.4/§6.4) already distinguishes a system that merely exists *within* universal HAPPENS from one that generates its own. State 1 — "EXISTS within HAPPENS" — is embedded in the universe's closed temporal structure, "carried by universal time," with no local closure: only a forward arc, riding the retarded propagator. State 3 has "a forward arc and a backward arc simultaneously active," a closed transaction generating its own local time. The universe's backward arc is structurally present everywhere; it is not, for a State-1 subsystem, a detectable local signal.

We name what this entails:

> **Universal Embedding Principle.** Every post-activation physical process is embedded in the universe's closed causal history; but only locally closed systems generate an internal HAPPENS clock and their own advanced arc. *Participation in universal closure is not generation of local advanced propagation.*

Status: entailment. It is not an added axiom; it follows from States 1 and 3 together with the universal/local time distinction that the Clock-Separation Theorem proves to be forced. It replaces a stronger principle one might be tempted to state — that the Hopf-torus pairing is a property of universal temporal structure as such — which is not proved and is not assumed here.

The Principle has a precise mathematical home. Represent the complete universal history by the closed-time-path generating functional

$$Z[J^+,J^-] = \mathrm{Tr}\big(U[J^+]\,\rho_U\,U^\dagger[J^-]\big),$$

with $U[J^+]$ the forward amplitude branch and $U^\dagger[J^-]$ the adjoint branch required for probabilities. When the branches carry identical sources, $Z[J,J] = \mathrm{Tr}(U\rho U^\dagger) = \mathrm{Tr}\,\rho = 1$: that is global closure. A local subsystem S receives only the reduced state $\rho_S = \mathrm{Tr}_{\bar{S}}(U\rho U^\dagger)$; operationally its records evolve entirely forward and retarded, and the backward branch need not appear as a locally detectable advanced signal. This is exactly how closed-time-path and influence-functional formulations describe globally two-branch probabilities while permitting ordinary causal reduced dynamics. The two clocks of the framework take distinct jobs: universal time T labels the complete history in which forward and adjoint branches close; internal time τ_i generates a particular system's local sequence of records. (Two things are called "internal" in this framework and must be kept apart: the STF scalar's own Compton phase Θ_s, treated in the Clock-Separation Theorem, and a subsystem's experiential/record clock τ_i, meant here. They are not generally the same clock.) They are not competing clocks. They act at different levels of description — and the retarded/advanced T^2 doubling of the topological sector is here proposed to correspond to the Schwinger–Keldysh doubling that any retarded response kernel requires. The correspondence is a dictionary, not yet a derivation: in the closed-time-path formalism the backward branch is the adjoint bookkeeping needed for in-in expectation values, not automatically a physically propagating advanced field, and $Z[J,J] = 1$ follows from unitarity and normalization alone. Establishing the identification would require an explicit map preserving composition, normalization, causal response functions, and observables. What is claimed here is that the two doublings have the same shape and the same division of labour — which is exactly the finding the earlier audit predicted would decide whether the STF torus is physics or analogy.

4. The two-clock transaction functional

Topological Closure V6.3 establishes, for a closed loop γ in the sphere of null directions with Hopf preimage T^2_γ, the primitive winding forms $\omega_R = i\,d\theta$ (Hopf sector) and $\omega_A = -i\,d\tilde{\theta}$ (anti-Hopf sector), with first Chern classes +1 and −1, and the pairing

$$\int_{T^2_\gamma} \omega_R \wedge \omega_A = 4\pi^2.$$

Introduce the anti-linear real-structure map $J : H^1_R \to H^1_A$ defined by $J(\omega_R) = \omega_A$ and $J(c\omega_R) = \bar{c}\omega_A$. It exchanges the Hopf and anti-Hopf sectors, complex-conjugating coefficients, without restricting the complexified geometry to its real fixed locus.

The existing restriction map sends a retarded Green-function class to the primitive generator, $[\Psi_R] \mapsto [\omega_R]$, retaining only the winding class. To describe alternative outcomes one must retain the coefficient. For outcome k write $r(\Psi^R_k) = A_k\omega_R$, with A_k the dynamical amplitude fixed by preparation, detector setting, and source coupling; the conjugate advanced class is $r(\Psi^A_k) = J(r(\Psi^R_k)) = \bar{A}_k\omega_A$. Define the universal transaction pairing

$$D_U(k,\ell) = \frac{1}{4\pi^2}\int_{T^2_\gamma} r(\Psi^R_k) \wedge r(\Psi^A_\ell) = A_k\bar{A}_\ell\;\frac{1}{4\pi^2}\int_{T^2_\gamma}\omega_R \wedge \omega_A = A_k\bar{A}_\ell.$$

The $4\pi^2$ cancels exactly; its role is to normalize the topological integral for one complete universal transaction — it does not normalize the amplitudes, which must separately satisfy $\Sigma_k|A_k|^2 = 1$. D_U is Hermitian, $D_U(\ell,k)^* = D_U(k,\ell)$; positive semidefinite, $\Sigma\, \bar{c}_k D_U(k,\ell)c_\ell = |\Sigma\, \bar{c}_k A_k|^2 \geq 0$; and its diagonal $D_U(k,k) = |A_k|^2$ has the form of a Born weight. **Status: algebraic lemma, conditional on the anti-linear outcome-fiber map J, on the Hilbert-space interpretation of the coefficients A_k (additional matter-sector structure), and on the amplitude normalization.** The identification of the diagonal with a probability is made in §7, where its status is priced.

The off-diagonal terms $A_k\bar{A}_\ell$ are interference. Attach to each outcome an internal-clock record state $|R_k(\tau_I)\rangle$, so that $\Omega^R_k = A_k\omega_R \otimes |R_k\rangle$ and $\Omega^A_\ell = \bar{A}_\ell\omega_A \otimes \langle R_\ell|$. The full two-clock decoherence functional is

$$D_{\mathrm{STF}}(k,\ell) = A_k\bar{A}_\ell\,\langle R_\ell(\tau_I)|R_k(\tau_I)\rangle.$$

Universal closure supplies the retarded–advanced transaction and its normalization; the internal clock orders the formation and persistence of the record states, while their dynamical entanglement with the apparatus and environment determines their overlap and hence whether alternatives remain coherent. Before a record forms, $\langle R_\ell|R_k\rangle \neq 0$ and interference survives; after a stable record, $\langle R_\ell|R_k\rangle \approx \delta_{k\ell}$ and $D_{\mathrm{STF}} \approx \delta_{k\ell}|A_k|^2$, so that $p_k = |A_k|^2/\Sigma_j|A_j|^2 = |A_k|^2$ for normalized exhaustive alternatives. This is the measured/observed distinction stated exactly: universal — relations among all closed histories; internal — locally instantiated record *alternatives*, rendered orthogonal by decoherence (which of them is actual is the separate question of §8's Single-Transaction Ontology); observed statistically — the diagonal frequencies over completed transactions.

5. Bell amplitudes inside the functional

The Bell coefficient is not to be sought in the STF matter coupling. The cross-disformal coupling $\hat{g}_{\mu\nu} = g_{\mu\nu} + (1/B)(\partial_\mu\varphi\partial_\nu\mathcal{R} + \partial_\mu\mathcal{R}\partial_\nu\varphi)$ carries spacetime indices and no spinor indices; it is spin-blind, universal, tied to curvature gradients, negligible in laboratory

Bell settings, and cannot produce an antisymmetric tensor — and it would risk predicting curvature-dependent Bell correlations, which are not observed. The coefficient comes instead from representation theory.

The same conclusion holds, and can be *proved*, for the framework's photon coupling. Write the STF-modified Maxwell sector as $L = -\frac{1}{4}Z(\varphi)F_{\mu\nu}F^{\mu\nu}$ with $Z(\varphi) = 1 + g_{\varphi\gamma}\delta\varphi$, in the normalization of the canonical First Principles V7.9 photon term $-\frac{1}{4}g_{\varphi\gamma}\delta\varphi F^2$ (this is the definition of $g_{\varphi\gamma}$ used throughout; an earlier draft wrote $Z = 1 - 4g_{\varphi\gamma}\varphi$ in the unnormalized convention, which differs by a sign and a factor of four); variation gives $\nabla_\mu[Z(\varphi)F^{\mu\nu}] = j^\nu$, a spacetime-dependent electromagnetic normalization. In geometric optics the leading-order equation is $Z(\varphi)[k^2a^\nu - k^\nu(k\cdot a)] = 0$, so with transverse gauge and $Z \neq 0$ both polarizations propagate on the same null cone $k^2 = 0$ — no birefringence, no preferred axis — and the next-order transport $\nabla_\mu[Z|a|^2k^\mu] = 0$ rescales both polarizations by a common factor. On the polarization Hilbert space the propagator is $K_\varphi = c_\varphi\mathbb{1}$, commuting with every analyzer rotation; for an entangled pair $(K_A \otimes K_B)\rho_{AB}(K_A^\dagger \otimes K_B^\dagger) = |c_Ac_B|^2\rho_{AB}$, so after normalization $\rho'_{AB} = \rho_{AB}$ exactly and every Bell correlation, including $S_{max} = 2\sqrt{2}$, is unchanged; a common detection efficiency $\eta_A(\varphi)\eta_B(\varphi)$ cancels from coincidence-conditioned probabilities under fair sampling; and a free on-shell plane wave has $F_{\mu\nu}F^{\mu\nu} = 2(B^2 - E^2) = 0$ and does not classically source φ. The cancellation holds under stated conditions — a slowly varying classical $Z(\varphi)$, geometric-optics propagation, polarization-independent local filtering, no relevant frequency- or polarization-entanglement with the background, and fair sampling or properly modelled losses; a single free plane wave has $F^2 = 0$, but arbitrary optical superpositions, the nonlinear-crystal fields of the source, and near fields need not. The remaining non-cancelling channel evaluated in the present effective-theory audit is the quantum vertex $\varphi \leftrightarrow \gamma\gamma$ (source-region, gradient, higher-operator, and frequency-entanglement effects lie outside the cancellation proof). On-shell production is excluded kinematically and the virtual channel is bounded (not closed) dynamically: an on-shell scalar of mass $m_s = 3.94\times10^{-23}$ eV can only decay to photons of 2×10^{-23} eV (wavelength ~6.7 light-years), 10^{23} times below the ~1.5 eV optical pairs of the cosmic Bell experiment, which were produced by spontaneous parametric down-conversion; the background phase drifts by $\sim6\times10^{-5}$ over a 17-minute run and is uniform to one part in 10^{13} across the apparatus; and in the sequestered UV realization of First Principles §L.11 — visible gauge kinetics depend on the local cycle, $\partial\tau_s/\partial\tau_b \approx 0$ — the tree-level visible-photon coupling vanishes (the photon term of the canonical V7.9 action, June 2026 revision, is written in this normalization), $g^{tree}_{\varphi\gamma} = 0$, leaving a volume-suppressed residual $g^{eff}_{\varphi\gamma} = c_\gamma/(\mathcal{V}M_{Pl}) \lesssim 1.4\times10^{-21}$ GeV^{-1} ($\mathcal{V} > 175$, $|c_\gamma| \lesssim 0.612$ taken by analogy with the matter sector — an assumption, not a theorem), whose virtual exchange at optical energies is $|\mathcal{M}| \lesssim 5\times10^{-60}$. Hence

$$S_{\rm STF} = S_{\rm QM} + O\left(\frac{E^2}{\mathcal{V}^2M_{\rm Pl}^2}\right), \qquad \text{interaction-amplitude estimate } |\mathcal{M}_\phi| \sim 10^{-59}\text{–}10^{-60} \text{ under the stated couplingassumptions.}$$

Status: conditional propagation-and-filtering lemma for the cancellation (valid under the listed conditions); **kinematic theorem** for the on-shell energy exclusion; **established, conditional on $|c_\gamma|$** for the sequestered bound; and the CHSH figure below is a *parametric interaction-amplitude estimate*, not yet a direct bound on δS_{Bell} — a map from the interaction amplitude through the propagated density matrix and detector channel to the normalized CHSH statistic has not been carried out. The conceptual weight of this result is that it closes the door the framework might otherwise be tempted to walk through: the STF scalar *cannot* be the Bell mechanism — it is too decoupled, too uniform, and too slow — so the reconciliation of Bell correlations must reside where §3–§4 place it, in the global retarded/advanced closure and the two-clock architecture, with ordinary quantum electrodynamics supplying the local measurements. Two independent routes — the representation-theoretic one above and the coupling audit here — arrive at the same division of labour. Let the detector eigen-spinors satisfy $(a\cdot\sigma)u_A(a) = A\,u_A(a)$ and $(b\cdot\sigma)u_B(b) = B\,u_B(b)$, and let the amplitude be bilinear, $A^{ab}_{AB} = T_{\alpha\beta}\,u^\alpha_A\,u^\beta_B$. For a total-spin-zero source the amplitude is invariant under a common SU(2) rotation, $U^TTU = T$; since $2 \otimes 2 = 3 \oplus 1$, there is exactly one invariant, $\varepsilon_{\alpha\beta}$, so $T = C\varepsilon$ with $|C| = 1/\sqrt{2}$ by normalization:

$$A^{ab}_{AB} = \tfrac{1}{\sqrt{2}}\,\varepsilon_{\alpha\beta}\,u^\alpha_A(a)\,u^\beta_B(b), \qquad |A^{ab}_{AB}|^2 = \tfrac{1}{4}\,(1 - AB\,\mathbf{a}\cdot\mathbf{b}).$$

Status: theorem (unique invariant of two doublets). Inserted into D_{STF} with orthogonal detector records, $P(A,B|a,b) = \frac{1}{4}(1 - AB\, a\cdot b)$, and $\Sigma_B P = \frac{1}{2}$ independent of b. The correct statement of the division of labour is: global closure consistently *hosts* the Bell amplitude and its adjoint; standard quantum representation theory supplies the correlation. For the optical experiments this paper is concerned with, the operative form is the photon one, $E(a,b) = -\cos 2(a-b)$, with the spin-½ $E = -a\cdot b$ as its Bloch-vector avatar (§5, below). The same Hopf map $S^1 \hookrightarrow S^3 \simeq SU(2) \to S^2$ that the null-cone geometry uses is the map from an analyzer direction on S^2 to a spinor ray in CP^1, which is why the framework's Fubini–Study kernel produced $\cos^2(\alpha/2)$: the half-angle is the $SU(2) \to SO(3)$ double cover, not a coincidence.

The construction is *proposed* to extend to other spins, and the proposal is kinematic. Scalar, Dirac, and Maxwell operators share the same characteristic variety — the null cone $k^2 = 0$ (for Dirac, $(\gamma\cdot k)^2 = k^2\cdot1$ gives $\det \propto (k^2)^2$; mass is lower order) — hence the same sky S^2 and the same Hopf lift. Shared characteristics determine wavefront propagation; they do not by themselves supply the outcome-fiber adjoint, the bundle structure, or the quantum inner product. Spin would live in an associated fiber over T^2_γ, and here a correction to an earlier draft is required: the Hopf fibration is a principal **U(1)** bundle, not a principal SU(2) bundle — its total space is $S^3 \simeq SU(2)$ as a space, which does not make SU(2) its structure group. What the Hopf bundle furnishes for free are the helicity line bundles $L_h = P_{Hopf} \times_{U(1)} \mathbb{C}_h$; *a full spin-s SU(2) representation requires a separately defined spin-frame principal bundle or associated fiber over the sky. Granting such a fiber, for* $\Psi^R_{s,k} = A_k\omega_R \otimes v_k$ and $\Psi^A_{s,\ell} = \bar{A}_\ell\omega_A \otimes v^\dagger_\ell$ one obtains $D_s(k,\ell) = A_k\bar{A}_\ell\langle v_\ell|v_k\rangle$, positive on the physical fiber. Topological Closure V6.3 states that its own higher-spin generalization remains open, and this paper does not close it. Helicity phases cancel between fiber and conjugate fiber, so no $h\cdot4\pi^2$ factor appears; the topology closes on the base while the fiber contributes the ordinary inner product. For photons, with polarizer angle a mapping to the Poincaré vector $n(a) = (\cos 2a, \sin 2a, 0)$, the antisymmetric two-photon state gives $E(a,b) = -\cos 2(a-b)$, the optical Bell correlation. Maxwell positivity requires gauge reduction to the transverse quotient $V_\gamma \simeq \mathbb{C}^2$; on the unreduced covariant space the positivity claim fails. **Status: kinematic proposal**, pending a correct spin-frame bundle and the outcome-fiber adjoint of §8.

6. Why sub-threshold laboratories exhibit Bell violations

Ordinary Bell laboratories are nowhere near the STF gravitational curvature-rate threshold. If every Bell transaction required a local STF activation, the account would fail at once. The Universal Embedding Principle is what prevents this. Distinguish

$$\chi_U(T_U) = \begin{cases} 0 & \text{before first global activation} \\ 1 & \text{after} \end{cases}, \qquad \chi_{\text{local}}(x) = \Theta\big(\mathcal{D}(x) - \mathcal{D}_{\text{crit}}\big).$$

χ_U governs whether the universe possesses the shared temporal and causal-closure structure at all; χ_{local} governs whether the STF scalar produces additional local dynamical backreaction. After cosmic activation $\chi_U = 1$ throughout the universal temporal domain, even where $\chi_{local} = 0$. A laboratory can therefore exhibit Bell correlations without any measurable STF scalar anomaly: the detectors and photons exist within universal HAPPENS, and neither needs to generate a new gravitational-channel activation. This is the framework's own claim — universal time as a persistent shared background after first activation, with local systems instantiating their own loops — doing exactly the work required.

7. The status of the whole: inherited, not derived

This paper's central claim requires one sentence of exactness, and it is the sentence on which the framework's credibility in this domain rests. **The Born rule is not derived above; it is inherited.** Trace $|A_k|^2$ to its source: $D_U(k,\ell) = A_k\bar{A}_\ell$, which follows from the anti-linearity of J — $J(c\omega_R) = \bar{c}\omega_A$. That anti-linearity is well motivated by geometry: the anti-Hopf bundle is the conjugate of the Hopf bundle, Chern class −1 against +1. But nothing in the torus *forces* the pairing of the conjugate sector to be anti-linear; a linear J would give A_kA_ℓ, no positivity, no Born rule. The choice that produces sesquilinearity is precisely the Hilbert-space structure being assumed. Likewise the singlet amplitude is imported from representation theory (correctly), and the record decoherence $\langle R_\ell|R_k\rangle \to \delta_{k\ell}$ is standard environment-induced decoherence with the internal clock as record.

The accurate status of what has been built is therefore a **consistent embedding**: a Hopf-torus-flavored, two-clock, transactional and consistent-histories reading of quantum mechanics — in the family of Cramer, Kastner, and Gell-Mann–Hartle, all already cited in General Theory — in which $4\pi^2$ normalizes one transaction, the anti-Hopf conjugation supplies the sesquilinear pairing, matter representations supply amplitudes, and internal clocks supply records. The headline is *STF is Born-compatible and Bell-compatible*, not *STF derives Born*. And that is a strong result, correctly stated. An earlier audit asked whether the framework's retarded/advanced topology is physics or only analogy. The answer earned here is a third thing: a faithful mathematical embedding of quantum structure into the causal-loop geometry, with the retarded/advanced pair mapping onto the ket/bra pair and the T^2 doubling onto the Keldysh contour. The framework was told it was not yet in the room where Bell predictions are made. It has walked in and sat down without contradiction.

8. The theorem that would change the status

What is not derived is the map from universal closure to local quantum probabilities. Stated exactly, the framework needs a **universal-to-local gluing theorem** of the form

$$\frac{1}{4\pi^2}\int_{T_U^2} \big\langle r(C_\beta),\, r(C_\alpha)\big\rangle = \mathrm{Tr}\big(C_\alpha\, \rho_U\, C_\beta^\dagger\big),$$

whose left side is the Hopf/anti-Hopf universal closure and whose right side is the decoherence functional $D(\alpha,\beta)$ for alternative histories, with $p(\alpha) = D(\alpha,\alpha)$ when records decohere. The $4\pi^2$ topology fixes a closure normalization; it does not by itself determine the density operator, the measurement operators, the singlet state, or the complete Born functional. The equality cannot be assumed. Its sharpest form is this: **derive the anti-linearity of J from the geometry** — from the complex structure or CPT of the complexified null cone, or from the unitarity and normalization identities of the Keldysh doubling that the T^2 construction has here been identified with. If J's anti-linearity is forced rather than chosen, one presently inherited ingredient of the Born construction — the sesquilinear, positive pairing — becomes derived; the complete Born rule would not thereby be derived (see the list above), but the framework would hold a result no other has. Stated at its proper generality this is the **Outcome-Fiber Adjoint Theorem**: the Lorentzian real structure that maps the retarded STF propagator to the advanced one must also map every complete retarded matter-and-record amplitude to its Hermitian adjoint. Topological Closure V6.3 establishes the propagator pairing and its $4\pi^2$ normalization; it does not yet extend the adjoint relation to detector-record fibers. If it does, positivity and sesquilinearity cease to be independent assumptions — but the Born rule would not thereby be *derived*: a full derivation would still require the physical amplitude space and its positive inner product, normalization, additivity under exclusive alternatives, composition for independent systems, the probability interpretation of the diagonal, an instrument structure, and an operational or noncontextuality assumption. Until then, the rule $p(A,B|a,b) = \mathrm{Tr}[W_U(M_A \otimes M_B)]$ — the generalized Born rule of quantum networks, with $W_U = \Sigma_e A_{\alpha e}\bar{A}_{\beta e}$ the universal closed history and M_A, M_B the operations on local clocks — is the exact mathematical target this framework must reach, not a derivation it has made. And $W_U \geq 0$ is a decoherence kernel, not yet a *process matrix* in the sense of Oreshkov–Costa–Brukner: that name requires normalized probabilities for every allowed collection of local CPTP operations, which imposes further linear constraints not proved here.

Actualization. Even a completed W_U supplies probabilities, not a unique experienced outcome. Two things can be said exactly. First, the *terminal boundary* the framework invokes must be a **macro**condition. Time-neutral quantum mechanics with initial and final conditions gives $D_F(\alpha,\beta) = \mathrm{Tr}(\rho_F C_\alpha \rho_I C_\beta^\dagger)/\mathrm{Tr}(\rho_F \rho_I)$ (the closed-system form of Aharonov–Bergmann–Lebowitz). A neutral final boundary $\rho_F \propto I$ recovers ordinary decoherent-histories quantum mechanics but selects no outcome; a pure outcome-specific final state $|F\rangle\langle F|$ selects but generically departs from Born statistics and, as Hartle showed, starves the environment of the records decoherence needs. The framework's heat death — maximum entropy, maximum homogeneity, no internal structure, an attractor — is thermodynamic language for a large terminal macro-subspace, $\rho_F \propto P_{HD}$, maximally mixed over the microstates satisfying it. Such a boundary is fixed enough to anchor the universe's outer transaction, and — being indifferent to the microscopic records of ancient laboratory events — coarse enough that $P_{HD} \approx I_{records} \otimes P_{rest}$ and Born statistics survive: $p(\alpha|HD) \approx \mathrm{Tr}(C_\alpha \rho_I C_\alpha^\dagger)$. Two conditions attach. In a cosmological quantum field theory the identity is not trace-class, so $\rho_F \propto P_{HD}/\dim H_{HD}$ presupposes a finite-dimensional or regulated macro-subspace, or must be replaced by an algebraic (KMS-type) macrostate; and record-indifference requires more than the factorization $P_{HD} \approx I \otimes P_{rest}$ — the rest-sector weighting must remain approximately branch-independent after the intervening dynamics. Born recovery is conditional on that stronger neutrality. The universal terminal boundary closes the universe without micromanaging any detector. The canonical General Theory V3.1 (June 2026 revision, deploying with this paper) has been amended to say *macrostate* explicitly. Second, the remaining step is not a theorem and cannot be made one on the present formalism: **$4\pi^2$ distinguishes closed from open, not outcome A from outcome B.** There are infinitely many maps $\gamma : S^1 \to \mathscr{C}_T(M)$ in one winding class, and every record section over the torus inherits the same normalization $(1/4\pi^2)\int s_\alpha$*$(\omega_R \wedge \omega_A) = 1$. This is the one-bit lemma stated back at the framework's own probability construction. "One real history" is therefore an ontological identification — the **Single-Transaction Ontology**: HAPPENS is one actual globally closed history α*, and quantum amplitudes weight the counterfactual closed histories that did not happen — priced, in this framework's discipline, as a *commitment*, alongside M = S. It is a contextual single-history realism: one actual outcome pair per performed context; no value table for unperformed settings (Bell excludes local counterfactual definiteness, not one actual history); nonfactorizable global weights; no controllable remote signal. Wavefunction collapse is then conditionalization on an objective record — the universal history already contains R_k; the internal clock's description is restricted to the portion of the actual history it has reached — perspectival without being subjective, and requiring no consciousness for a detector to click. No selection mechanism exists in the present STF closure formalism, and the framework should *not* seek to supply one by giving the STF scalar a nonlinear collapse dynamics: generic deterministic nonlinear modifications of quantum evolution permit EPR signaling (Polchinski; Simon–Bužek–Gisin), and no-signaling forces density-matrix dynamics toward linear completely positive maps. Other selection ontologies — stochastic dynamics, hidden beables — are not thereby excluded; they are simply not STF. One further requirement, following Gell-Mann and Hartle's one-real-history formulation: α^* must be defined relative to a specified fine-grained history space and a decoherent family or coarse-graining, with a rule relating compatible families — otherwise "one global history" is ill-defined across incompatible consistent-history sets.

What remains open after that is the last honest item: **Repeated-Transaction Typicality** — why the one actual history is typical with respect to the closure measure across the millions of trials it contains, and why independently prepared transactions approximately factorize, $D_N \approx \Pi_n D_n$. That is the same problem every one-real-history formulation faces, and it is where this framework's account of quantum probability now ends.

9. Falsifiers

1. **Curvature- or scalar-background-dependent Bell correlations.** §5 proves that a classical STF background rescales both photon polarizations identically ($\rho'_{AB} = \rho_{AB}$) and that the sequestered photon coupling perturbs CHSH by at most $O(E^2/\mathscr{V}^2 M_{Pl}^2)$. A measured dependence of normalized Bell correlations on local curvature rate, on the STF phase (3.32-yr period), or on any polarization-independent background — birefringence, a preferred axis, or a CHSH deficit tracking the scalar — would contradict §5 and indicate that the STF field was, after all, acting as a local mechanism.
2. **Bell violations sensitive to χ_{local}.** If Bell violations were found to require, or to be modulated by, local STF activation (curvature-rate threshold crossing), the Universal Embedding Principle's χ_U/χ_{local} separation would fail.
3. **A signaling retrocausal effect.** Any use of the STF backward arc to transmit a controllable signal between spacelike-separated detectors would contradict the no-signaling marginals of §5 (a single controllable bit would suffice; the one-bit lemma bounds bandwidth, not signalling, and is not itself contradicted).
4. **For the embedding itself:** exhibit a physically motivated *linear* pairing of the anti-Hopf sector that reproduces observed statistics. Positivity would fail and §4 would have to be abandoned. No such pairing is known; the anti-linear choice is the only one consistent with observation, which is exactly why it is a choice and not yet a theorem.

Appendix A — Derivation record: the transaction functional and the singlet chain

The external derivations this paper's §4–§5 rest on, with independent verification status. This appendix is the primary derivation; the verbatim audit documents (`STF_Audit_Record_2026-06-14_Part2.md`, D5 and continuations) and the verification log are supplementary provenance, to be published alongside the paper. Labels: ***verified*** *= reproduced symbolically/numerically;* ***corpus-verified*** *= framework statement checked verbatim against the deployed paper.*

A.1 The pairing. On T^2_γ: $\omega_R = i\, d\theta$ (Hopf), $\omega_A = -i\, d\tilde{\theta}$ (anti-Hopf), $\int \omega_R \wedge \omega_A = 4\pi^2$ (Topological Closure V6.3, Heegaard transgression). Anti-linear real-structure map $J: H^1_R \to H^1_A$, $J(\omega_R) = \omega_A$, $J(c\omega_R) = \bar{c}\omega_A$. Retain the outcome coefficient before the residue: $r(\Psi^R_k) = A_k\omega_R$, $r(\Psi^A_k) = J(r(\Psi^R_k)) = \bar{A}_k\omega_A$. Then $D_U(k,\ell) = (1/4\pi^2)\int r(\Psi^{R}_k)\wedge r(\Psi^{A}_\ell) = A_k\bar{A}_\ell\cdot(1/4\pi^2)\int\omega_R\wedge\omega_A = A_k\bar{A}_\ell$. Hermitian; PSD ($\Sigma \bar{c}_k D_U c_\ell = |\Sigma \bar{c}_k A_k|^2 \geq 0$); diagonal $|A_k|^2$. **[verified; corpus-verified: TC lines 65, 189–193 for ω_R, ω_A, Hopf/anti-Hopf with Chern ±1.]**

A.2 Internal-clock records. $\Omega^R_k = A_k\omega_R \otimes |R_k(\tau_I)\rangle$, $\Omega^A_\ell = \bar{A}_\ell\omega_A \otimes \langle R_\ell(\tau_I)|$; $D_{STF}(k,\ell) = A_k\bar{A}_\ell\langle R_\ell|R_k\rangle$; interference before recording ($\langle R_\ell|R_k\rangle \neq 0$), Born-diagonal after ($\langle R_\ell|R_k\rangle \approx \delta_{k\ell}$); $p_k = |A_k|^2$ for normalized exhaustive alternatives. Universal/internal/measured/observed distinction as in §4. **[standard decoherence, correctly deployed.]**

A.3 The singlet, uniquely. Detector eigen-spinors $(a\cdot\sigma)u_A = Au_A$, $(b\cdot\sigma)u_B = Bu_B$; bilinear amplitude $T_{\alpha\beta}u^{\alpha}_{A}u^{\beta}_{B}$; total spin zero ⇒ invariant under common $U \in SU(2)$: $U^T T U = T$; $2\otimes 2 = 3 \oplus 1 \Rightarrow T = C\varepsilon_{\alpha\beta}$, unique; $|C| = 1/\sqrt{2}$ by normalization ⇒ $A^{ab}_{AB} = (1/\sqrt{2})\varepsilon_{\alpha\beta}u^{\alpha}_{A}(a)u^{\beta}_{B}(b)$; $|\varepsilon\, u_A u_B|^2 = \tfrac{1}{2}(1 - AB\, a\cdot b) \Rightarrow |A^{ab}_{AB}|^2 = \tfrac{1}{4}(1 - AB\, a\cdot b)$; marginal ½. Not from the STF cross-disformal coupling $\hat{g}_{\mu\nu} = g_{\mu\nu} + (1/B)(\partial_\mu\varphi\partial_\nu\mathcal{R} + \partial_\mu\mathcal{R}\partial_\nu\varphi)$, which is spin-blind. **[verified: $U^T\varepsilon U = \det(U)\varepsilon = \varepsilon$ for generic SU(2); spinor identity to 10^{-17} at random settings; corpus-verified: FP cross-disformal coupling as a separate matter-sector input.]** Hopf link: $a \in S^2$ lifts to $[u(a)] \in CP^1$ via $a = u^\dagger\sigma u$; the Fubini–Study half-angle $\cos^2(\alpha/2)$ of Null Cone V1.0 is the $SU(2) \to SO(3)$ double cover. **[corpus-verified: NC line 314.]**

A.4 Higher-spin kinematic extension. Shared characteristic variety: KG $\sigma(P_0,k) = g^{\mu\nu}k_\mu k_\nu$; Dirac $\sigma(P_{1/2},k) = \gamma^\mu k_\mu$ with $(\gamma\cdot k)^2 = k^2 I \Rightarrow \det \propto (k^2)^2$; Maxwell transverse modes $k^2 = 0$; mass lower-order ⇒ same sky S^2, same Hopf lift $S^1 \hookrightarrow S^3 \simeq SU(2) \to S^2$, same T^2_γ. Associated fiber over T^2_γ (NB: the Hopf fibration is principal U(1), not SU(2); helicity line bundles $L_h = P_{Hopf} \times_{U(1)} \mathbb{C}_h$ come for free, a full spin-s fiber needs a separate spin-frame bundle — corrected on review); $\Psi^R_{s,k} = A_k\omega_R \otimes v_k$, $\Psi^A_{s,\ell} = \bar{A}_\ell\omega_A \otimes v^\dagger_\ell$; $D_s(k,\ell) = A_k\bar{A}_\ell\langle v_\ell|v_k\rangle$; helicity phases $e^{ih\chi}e^{-ih\chi}$ cancel (no $h\cdot 4\pi^2$); positivity via $|\Phi_k\rangle = A_k|v_k\rangle$; Maxwell requires gauge reduction to $V_\gamma \simeq \mathbb{C}^2$ (positivity fails on the unreduced space); photons $n(a) = (\cos 2a, \sin 2a, 0) \Rightarrow E = -\cos 2(a-b)$; Dirac inner product $(\psi,\chi)_\Sigma = \int\bar{\psi}\gamma^\mu n_\mu\chi$ positive on positive-frequency solutions. $H_{total} = H_U \otimes H_{matter} \otimes H_{record}$. **[verified: Clifford characteristic cone, helicity cancellation, photon angle-doubling; kinematic status only.]**

A.5 Sub-threshold laboratories. $\chi_U(T_U) \in \{0,1\}$ (universe possesses closure after first activation) vs $\chi_{local}(x) = \Theta(\mathscr{D}(x) - \mathscr{D}_{crit})$; $\chi_U = 1$ everywhere post-activation even where $\chi_{local} = 0$. **[corpus-verified: ToT — universal time persistent after first activation; GT States 1/3.]**

A.6 Photon-sector cancellation and sequestering (D8b–d). $L = -\tfrac{1}{4}Z(\varphi)F^2$, $Z = 1 + g_{\varphi\gamma}\delta\varphi$ (canonical FP V7.9 normalization; D8 used the unnormalized $Z = 1 - 4\beta\varphi$); $\nabla_\mu[ZF^{\mu\nu}] = j^\nu$; geometric optics ⇒ $k^2 = 0$ for both polarizations, common transport $\nabla_\mu[Z|a|^2k^\mu] = 0$; $K_\varphi = c_\varphi\mathbb{1}$, $[K_\varphi,U(a)] = 0$; $(K_A\otimes K_B)\rho(K_A^\dagger\otimes K_B^\dagger) = |c_Ac_B|^2\rho \Rightarrow \rho' = \rho$; efficiency cancels under fair sampling; free wave $F^2 = 0$. Kinematics: $E_\gamma = m_s/2 = 1.97\times10^{-23}$ eV, $\lambda \approx 6.7$ ly vs 1.5 eV optical; phase drift 6×10^{-5} per 17 min; $L/\lambda_C \sim 10^{-13}$. Coupling: $g_{\varphi\gamma} = \partial_\varphi \ln \mathrm{Re}\, f_\gamma|_{\varphi_0}$ (not ζ/Λ); FP's displayed $(\alpha/\Lambda)\varphi F^2$ lacked the ¼ and overloaded α — corrected in the canonical First Principles V7.9 (June 2026 revision, deploying with this paper) to $-\tfrac{1}{4}g^{eff}_{\varphi\gamma}\delta\varphi F^2$ with a normalization note; §L.11 sequestering ⇒ $g^{tree}_{\varphi\gamma} = 0$; residual $c_\gamma/(\mathscr{V}M_{Pl}) \lesssim 1.4\times10^{-21}$ GeV^{-1}; $|\mathscr{M}| \lesssim 5\times10^{-60}$; $\tau_\varphi \gtrsim 10^{114}$ s. **[verified numerically: ρ′ = ρ exact, CHSH unchanged, efficiency cancellation, all kinematic numbers, decay-width convention (factor 16 between the ¼ and no-¼ conventions), sequestered bounds; corpus-verified: FP L463 boxed Lagrangian, L7224/7230 sequestering; narrowing: FP quotes no φ→γγ width, so the defect is the unnormalized/overloaded/unsequestered term, not a width mismatch.]**

A.7 Status. D5's own claim: "more than a resemblance, but not yet a finished STF theorem." This paper's ruling (§7): Born inherited via the anti-linear choice of J. The strong "Universal Transaction Principle" D5 proposed is not adopted (see Appendix B).

Appendix B — Derivation record: embedding, gluing, actualization, typicality

Supplementary provenance: `STF_Audit_Record_2026-06-14_Part2.md`, D6 and D7(a)–(c); this appendix is the primary derivation.

B.1 The retreat (D6). Strong principle (Hopf pairing = a property of universal temporal structure as such) is too strong and unproved. Replacement: the Universal Embedding Principle, from GT State 1 ("EXISTS within HAPPENS… carried by the global temporal structure"; "embedded in HAPPENS without local closure") vs State 3 (forward + backward arc simultaneously active). CTP form: $Z[J^+,J^-] = \mathrm{Tr}(U[J^+]\rho_U U^\dagger[J^-])$; $Z[J,J] = 1$ = global closure; $\rho_S = \mathrm{Tr}_{\bar{S}}(U\rho U^\dagger)$ evolves forward/retarded; universal T labels the two-branch closed history, internal τ_i the record sequence. Bell: $p(A,B|a,b) = \mathrm{Tr}[\rho_{AB}(M_{A|a} \otimes N_{B|b})]$ nonfactorizable; $p(A|a,b) = \mathrm{Tr}[\rho_{AB}(M_{A|a} \otimes I)]$ b-independent. Missing theorem named: $(1/4\pi^2)\int\langle r(C_\beta),r(C_\alpha)\rangle = \mathrm{Tr}(C_\alpha\rho_U C_\beta^\dagger)$; "$4\pi^2$ fixes a normalization, not ρ, the operators, the singlet, or the Born functional." KMS correction: Tr U(T) is a real-time trace; thermal only after imaginary-time continuation + equilibrium. **[corpus-verified: GT 241, 2527, 187; GT 896/4720–4744 (Gell-Mann–Hartle, Griffiths, Omnès already cited); GT §904–914 amended.]**

B.2 The gluing map (D7a). $\Psi_R = \Sigma_{\alpha,e}A_{\alpha e}\omega_R \otimes |\alpha,e\rangle$, $\Psi_A = \Sigma_{\beta,e}\bar{A}_{\beta e}\omega_A \otimes \langle\beta,e|$; $W_{\alpha\beta} = (1/4\pi^2)\Sigma_e\int A_{\alpha e}\bar{A}_{\beta e}\omega_R\wedge\omega_A = \Sigma_e A_{\alpha e}\bar{A}_{\beta e}$ — a positive decoherence kernel of reduced-density-matrix form, $W \geq 0$ (a *process matrix* in the OCB sense only if the additional operational normalization constraints are proved, which they are not here). Local clocks as instruments $\{M^A_{A|a}\}$, $\{M^B_{B|b}\}$; $p(A,B|a,b) = \mathrm{Tr}[W_U(M^A \otimes M^B)]$ — the generalized Born rule of process matrices (OCB, CDP). Singlet chain $\varepsilon \to |\psi^-\rangle \to W_- = |\psi^-\rangle\langle\psi^-| \to \tfrac{1}{4}(1 - AB\, a\cdot b) \to E = -a\cdot b$, marginal ½. Foliation independence: $[M^A,M^B] = 0 \Rightarrow p_{A\prec B} = p_{B\prec A}$. Detector clock may be a State-1 oscillator; consciousness not required for the click. "$4\pi^2$ normalizes closure; A_α determines probability ratios." Conditional Born derivation from: complex retarded amplitude space + anti-linear advanced adjoint + $4\pi^2$ normalization + additive local instruments + normalized noncontextual probabilities — of which STF proves only part; process matrices assume local quantum operations and linearity. Missing: **Outcome-Fiber Adjoint Theorem** (real structure $G_R \to G_A$ extends to every complete matter-and-record amplitude ↦ its Hermitian adjoint). **[verified numerically: W Hermitian/PSD; $\mathrm{Tr}[W_-(\Pi\otimes\Pi)] = \tfrac{1}{4}(1 - AB\, a\cdot b)$ to machine precision; E, marginal; commutator zero.]**

B.3 Terminal-boundary trilemma (D7b). $D_F(\alpha,\beta) = \mathrm{Tr}(\rho_F C_\alpha\rho_I C_\beta^\dagger)/\mathrm{Tr}(\rho_F\rho_I)$ (closed-system ABL). (A) $\rho_F \propto I$: Born ✓, no selection. (B) $\rho_F = |F\rangle\langle F|$: $p(\alpha|F) = |\langle F|C_\alpha|\psi_I\rangle|^2/\Sigma_\gamma|\langle F|C_\gamma|\psi_I\rangle|^2$, ABL postselection ≠ Born generically; a specific pure final state starves decoherence (Hartle 2020). (C) $\rho_F = P_{HD}/\dim H_{HD}$, heat-death macro-subspace, record-indifferent $P_{HD} \approx I_{records} \otimes$

$P\_rest \Rightarrow p(\alpha|HD) \approx Tr(C_\alpha \rho\_I C_\alpha^\dagger)$: Born recovered, closure retained. Hence “fixed terminal state” = thermodynamic macrostate, not a pure microstate. Reality condition $\exists! \alpha^* \in \Omega\_closed$, $Pr(\alpha^* = \alpha) = \mu(\alpha) = D\_F(\alpha,\alpha)$; collapse = internal-clock perspective on which part of the actual history one occupies; Bell: one actual pair (A,B), $\langle AB \rangle = -a\cdot b$, marginals ½, no wing collapses the other; setting independence $\rho\_I(\lambda|do\ a, do\ b) = \rho\_I(\lambda)$ preserved with nonfactorizable μ. Two options offered: single-transaction axiom, or dynamical uniqueness theorem. **[verified numerically: mixed record-indifferent P_HD recovers Born exactly; pure record-specific F departs (to impossibility of some outcomes); corpus-verified: GT characterizes heat death thermodynamically throughout — “macrostate” 0 hits, “unique terminal state” 0 hits; GT “single state” line amended to “single macrostate.”]**

B.4 The topological verdict (D7c). $\mathscr{C}\_T(M) \cong S^1$ and $\int\_{T^2}\omega\_R \wedge \omega\_A = 4\pi^2$ prove closure and winding, not a unique representative: infinitely many $\gamma: S^1 \to \mathscr{C}\_T(M)$ in one class; every record section $s\_\alpha: T^2 \to E\_rec$ inherits $(1/4\pi^2)\int s\_\alpha(\omega\_R \wedge \omega\_A) = 1$. ***4π² distinguishes CLOSED from OPEN, not outcome A from outcome B.*** *Category correction: $\mathscr{C}\_T(M)$ = possible transactions; $D(\alpha,\beta)$ = weighting functional;* α = the transaction that HAPPENS; HAPPENS = α*, not the configuration space or path integral. ⇒ Single-Transaction **Ontology** (identification, not theorem). Not a Bell hidden-variable model: no value table for unperformed settings, $\Omega\_ab \neq \Omega\_\{a'b\}$ as contexts; Bell excludes local counterfactual definiteness, not one actual history. Collapse = conditionalization: $D\_\tau(\alpha,\beta) = D(\alpha,\beta|I\_\tau)$; $p\_\{\tau+\}(A) = p(A|I\_\{\tau-\},R\_k) = \delta\_\{A,k\}$; objective record, internal-clock-relative certainty; $p(B|b) = ½$ local vs $p(B|A,a,b) = ½(1 - AB\ a\cdot b)$ global conditional. Do not add a nonlinear collapse field: Polchinski (EPR signaling); Simon–Bužek–Gisin (no-signaling ⇒ linear CP maps). Next theorem: **Repeated-Transaction Typicality** — $D\_N \approx \Pi\_nD\_n$ across independent trials; typical $E\_N \to -a\cdot b$. **[this paper’s sharpening: given B.4, the current STF closure formalism contains no selection dynamics; any such dynamics would be additional structure requiring its own compatibility and no-signaling analysis — it need not be nonlinear (stochastic dynamics or hidden beables are not excluded, only not STF); on the present formalism the status collapses to a single priced commitment. Typicality LLN-trivial numerically; content = proving factorization across independently prepared closures.]**

B.5 What the two appendices establish, in one line. Compatibility proved and priced (A); the target theorem named (Outcome-Fiber Adjoint), the terminal boundary corrected to a macrostate, actualization located as a commitment, and typicality named as the last open item (B).

References

Project papers (existshappens.com):

- *Topological Closure on the Complexified Null Cone* V6.3 — papers/topological-closure/ (Hopf/anti-Hopf sectors, ω_R, ω_A, Chern classes ±1; $\int \omega\_R \wedge \omega\_A = 4\pi^2$; restriction maps; higher-spin scope).
- *The Complexified Null Cone as the Geometric Seat of Retrocausal Activation* V1.0 — papers/null-cone/ (reguli; Fubini–Study half-angle kernel; cross-ratio classifier).
- *The Clock-Separation Theorem* V1.1 — (gradient-clock obstruction theorem; conditional clock-separation corollary; phase-lift completion conjecture).
- *The Structure of What Happens* (General Theory) V3.1 — papers/general-theory/ (four-state ontology; State 1 within HAPPENS; consistent-histories citations §896; ER=EPR aside).
- *Theory of Time* V4.3 — papers/theory-of-time/ (universal time as persistent background after first activation).
- *One Bit of Destiny* V1.0 — papers/one-bit-of-destiny/ (directional novelty; the one-bit lemma).
- *STF First Principles* V7.9 — papers/first-principles/ (cross-disformal matter coupling; photon coupling and its V7.9 normalization; §L.11 sequestering; retrocausal ancestry).

External:

- Aharonov, Y., Bergmann, P.G. & Lebowitz, J.L. (1964). “Time symmetry in the quantum process of measurement.” *Phys. Rev.* 134, B1410–B1416.
- Argaman, N. (2010). “Bell’s theorem and the causal arrow of time.” *Am. J. Phys.* 78, 1007–1013.
- Bell, J.S. (1964). “On the Einstein Podolsky Rosen paradox.” *Physics* 1, 195–200.
- Chiribella, G., D’Ariano, G.M. & Perinotti, P. (2009). “Theoretical framework for quantum networks.” *Phys. Rev. A* 80, 022339.
- Cramer, J.G. (1986). “The transactional interpretation of quantum mechanics.” *Rev. Mod. Phys.* 58, 647–687.
- Feynman, R.P. & Vernon, F.L. (1963). “The theory of a general quantum system interacting with a linear dissipative system.” *Ann. Phys.* 24, 118–173. (Influence functional.)
- Gell-Mann, M. & Hartle, J.B. (1990). “Quantum mechanics in the light of quantum cosmology.” In *Complexity, Entropy, and the Physics of Information*, ed. W.H. Zurek. Addison-Wesley.
- Gell-Mann, M. & Hartle, J.B. (2012). “Decoherent histories quantum mechanics with one real fine-grained history.” *Phys. Rev. A* 85, 062120.
- Handsteiner, J. et al. (2017). “Cosmic Bell test: measurement settings from Milky Way stars.” *Phys. Rev. Lett.* 118, 060401.
- Hartle, J.B. (2020). “Arrows of time and initial and final conditions in the quantum mechanics of closed systems like the universe.” arXiv:2002.07093.
- Hossenfelder, S. & Palmer, T. (2020). “Rethinking superdeterminism.” *Front. Phys.* 8, 139.
- Kastner, R.E. (2022). *The Transactional Interpretation of Quantum Mechanics: A Relativistic Treatment*, 2nd ed. Cambridge University Press.
- Keldysh, L.V. (1964). “Diagram technique for nonequilibrium processes.” *Sov. Phys. JETP* 20, 1018–1026.
- Oreshkov, O., Costa, F. & Brukner, Č. (2012). “Quantum correlations with no causal order.” *Nature Commun.* 3, 1092.
- Polchinski, J. (1991). “Weinberg’s nonlinear quantum mechanics and the Einstein–Podolsky–Rosen paradox.” *Phys. Rev. Lett.* 66, 397–400.

- Price, H. (1996). *Time's Arrow and Archimedes' Point.* Oxford University Press.
- Price, H. & Wharton, K. (2015). "Disentangling the quantum world." *Entropy* 17, 7752–7767.
- Rauch, D. et al. (2018). "Cosmic Bell test using random measurement settings from high-redshift quasars." *Phys. Rev. Lett.* 121, 080403.
- Schwinger, J. (1961). "Brownian motion of a quantum oscillator." *J. Math. Phys.* 2, 407–432.
- Simon, C., Bužek, V. & Gisin, N. (2001). "No-signaling condition and quantum dynamics." *Phys. Rev. Lett.* 87, 170405.
- Wharton, K.B. & Argaman, N. (2020). "Colloquium: Bell's theorem and locally mediated reformulations of quantum mechanics." *Rev. Mod. Phys.* 92, 021002.
- Wheeler, J.A. & Feynman, R.P. (1945). "Interaction with the absorber as the mechanism of radiation." *Rev. Mod. Phys.* 17, 157–181.

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