V131 Unified Causal Field — Quantum Foundations & Measurement Sector Supplement (v2.2-QFound)

> Supplement to the V131 cosmology reports (concept DOI 10.5281/zenodo.21153115, v2.1 record 10.5281/zenodo.21180901; site: milkyway.center/cosmology). The four field equations (1′)–(4′) are unchanged. Labels: **[EST]** = established mathematics/physics, attributed; **[V131]** = framework-specific claim; **[SPEC]** = not quantitatively closed. Corrections are kept on record per the framework's calibration principle (reported confidence = measured hit rate). Engineering implementations of the results below (timing constraints, decision-gate architectures, loss functions) are intentionally not disclosed here.

1. Postulate structure

V131's measurement sector rests on exactly **two postulates**; everything else in this document is a theorem given standard mathematics.

- **P1 (threshold trigger).** Causal fixing fires when the Bures/Fisher angle Θ accumulated along an irreversible record reaches Θ_c = π/2 (orthogonality).
- **P2 (contractive fixing).** Fixing is generated by a GKSL (Lindblad) dissipator — completely positive, trace-preserving, contractive, irreversible.

2. Kinematic theorems

T-A (speed-limit bound). For any recorder, the accumulation rate obeys the Mandelstam–Tamm bound [EST: Mandelstam–Tamm 1945; Fubini–Study speed], with the counter-rotating branch convention giving dΘ/ds ≤ 2ΔE/ħ. Hence

$$\tau_{\mathrm{fix}} \;\geq\; \frac{\pi\hbar}{4\,\Delta E},$$

an axiom-level inequality; equality holds for ideal recorders (maximal-variance pointer states). [V131: the claim that fixing *fires at* the threshold; the equality case; the ΔE-scaling of collapse completion.]

T-B (no-record theorem / discrimination orthogonality). If the environment branch states remain indistinguishable (fidelity 1), the loop is closable, Θ = 0, and fixing never triggers — at any mass. Consequently V131 predicts **zero intrinsic decoherence** in coherence-preserving interferometry (any mass) and **zero spontaneous heating** for energy eigenstates (ΔE = 0). The null results of LISA Pathfinder and γ-ray heating searches [EST: LPF; Donadi et al. 2021] are structural exemptions for V131, not parameter squeezes; the trigger is informational (records), strictly orthogonal to mechanical triggers (mass, position, gravitational self-energy) of GRW/CSL/DP. A confirmed *mass-scaled* intrinsic contrast loss, with environmental decoherence excluded, falsifies P1 outright.

T-C (statistical irreversibility). The global branch angle is unitary-invariant; the record angle is monotone under data processing [EST: fidelity monotonicity]; erasure requires re-coupling **all** record fragments, and with N-fold redundancy [EST: Zurek's quantum Darwinism] partial erasure of m < N fragments leaves Θ ≥ arccos(cos^{N−m}). Irreversibility of fixing is a statistical theorem, not a postulate.

T-D (Born rule as a theorem). Pointer-basis GKSL dynamics unravels with Fisher-innovation noise dp_k = 2√D p_k(a_k − ⟨A⟩)dW [EST: Belavkin / quantum-state diffusion]; population processes are martingales; combined with the Fisher-measure lemma (Bures-angle weights cos²θ_k = |c_k|²) [EST ingredients: Wootters 1981; Gleason 1957], single-outcome statistics reproduce |⟨k|Ψ⟩|². Within V131, Born is derived, not postulated.

3. Geometric dictionary [V131]

The open-system generalization of the framework's holonomy angle is the **Uhlmann holonomy** [EST: Uhlmann 1986] — Bures parallel transport on the purification bundle; the closed-system trace-torsion holonomy is its pure-state limit. The two irreducible parts of torsion are claimed by the two components of the quantum geometric tensor:

torsion irrep	geometric object	role
trace torsion $T^D{}_{DA}$	Re Q (Bures/Fubini–Study metric); along the history flow, twice the Bures speed	**rate channel** ("how fast"): the fixing clock, Θ of P1
axial torsion $\mathcal{A}_A = \frac{1}{3!}\varepsilon_A{}^{BCD}T_{BCD}$	Uhlmann connection (pure-state limit: Berry); curvature $F = d\mathcal{A} = -2\,\mathrm{Im}\,Q$	**sign/phase channel** ("which way"): entanglement holonomy, chirality/CP biases

Arc (metric channel) and phase (connection channel) coincide in magnitude only on geodesic loops (verified exactly on CP¹); on general histories they split — accordingly the framework's entanglement-holonomy exponent is carried by the axial 1-form (a notation correction recorded in the internal derivation documents; physical content unchanged). Numerically, the mixed-state Uhlmann phase exhibits the known topological purity transition; below critical purity the phase channel trivializes while the rate channel continues to accumulate — an independent corroboration of the two-channel assignment.

4. Energy-gap division of labor [V131]

With the v2.1 propagating-torsion bound α < 2×10⁻⁴⁵ m², the torsion mass gap is ħc/√α ≳ 4×10⁶ GeV. Below the gap (all laboratory physics), in-medium torsion is an enslaved field; integrating it out returns only the gravitational-strength contact interaction — no laboratory-scale intrinsic collapse channel exists (this *strengthens* T-B to a gap theorem). Above the gap (the early universe: reheating through freeze-out, ≥10¹³ × the gap), the torsion bath is a valid Markovian driver — the regime in which the framework's cosmological pipeline operates. One gap, two self-consistent regimes, no crossover process in between.

5. Falsification lines (measurement sector)

- **F5′ (Landauer ledger).** Each fixing event dissipates ≥ kT ln 2 per bit, time-locked to collapse completion (at 20 mK: 1.2 μeV/bit). A calibrated calorimetric deficit at measurement events kills the ledger. (Single-shot sensitivity is 2–3 orders beyond current calorimetry; ensemble protocols are feasible.)
- **F7′ (scaling discriminator).** Collapse completion time scales as 1/ΔE_pointer (quantum-speed-limit saturation), not with mass or gravitational self-energy. A confirmed mass-scaled intrinsic decoherence kills P1; sustained interferometric coherence at growing mass progressively excludes mechanical-collapse parameter space while leaving V131 untouched.

6. Honest boundaries

Ideal-recorder saturation of T-A is an approximation in real devices; the component-level ε-dual index bookkeeping on the full 9-dimensional manifold is deferred to a mathematical appendix; laboratory tests of F5′ await calorimetric sensitivity. This is a speculative framework: the theorems above are conditional on P1–P2, and P1–P2 are exactly where the experiments listed in §5 aim.

7. 中文摘要

V131 测量扇区的最终结构：**两条公设**（π/2 阈值触发；固定=GKSL 收缩），其余皆定理——速度极限下界 $\tau_{fix} \geq \pi\hbar/4\Delta E$（Mandelstam–Tamm）、无记录定理（本征退相干与自发加热严格为零，对 LISA Pathfinder/γ 射线零结果为结构豁免，与 GRW/CSL/DP 的力学触发严格正交）、不可逆性为统计定理（量子达尔文主义冗余）、玻恩定则为定理（Belavkin 解开 + Fisher 测度）。几何字典：挠率两个不可约部分逐分量认领量子几何张量——迹挠率↔Bures 度规（速率通道，"多快"），轴挠率↔Uhlmann 联络（相位/符号通道，"哪边"）。能隙分工：$\alpha < 2\times10^{-45}\ m^2 \Rightarrow$ 挠率质量隙 $\gtrsim 4\times10^6$ GeV，实验室为记录驱动区、早期宇宙为挠率浴驱动区，一条能隙、两个自洽区。证伪线 F5′（Landauer 热账本）与 F7′（ΔE 标度判别）锚定实验室时标。工程实现（时序约束、决策门架构、损失函数）本文有意不披露。

V131 project · Frank Huo · yuanjimaster@gmail.com · milkyway.center · 2026-07