EXPERIMENTAL TESTS FOR
POLARIZED TIME INERTIA

Revised Edition — Aligned with Corrected Axioms

Companion Document — March 2026

Abstract

This companion document proposes a comprehensive suite of experimental tests, observational programs, and falsification criteria for the revised Polarized Time Inertia (PTI) framework. Tests are organized by the three axioms and each major physical prediction. Every test specifies: the PTI prediction, the standard-physics prediction, the measurable difference, and the falsification condition. Tests are graded into three tiers by feasibility. This edition is aligned with the revised axioms—Relational Existence, Hierarchical Condensation, and Frame-Dependent Decomposition—and explicitly distinguishes between predictions that are already confirmed (being mathematically equivalent to established results) and novel predictions requiring new evidence.

1. Classification of PTI Claims

Before proposing tests, we classify each PTI claim into one of three categories:

Category A — Already confirmed: Claims that are mathematically equivalent to established physics and therefore already have extensive experimental support. These do not need new tests but demonstrate consistency.

Category B — Novel reinterpretation: Claims that offer a new physical mechanism for known phenomena. The phenomena are confirmed, but the mechanism is not. Tests must distinguish the PTI mechanism from the standard explanation.

Category C — Novel prediction: Claims that predict phenomena not predicted by standard physics, or that contradict standard predictions. These are the strongest test targets.

PTI Claim	Category	Status
Gravity as spatial flow (river model)	A	Mathematically equivalent to GR; confirmed
Photon null geodesic (τ=0)	A	Standard SR/GR; confirmed
Gravity is discrete at Planck scale	C	Novel prediction; untested
Space emerges from entanglement	B	Supported by AdS/CFT; not directly confirmed
QCD color ↔ spatial dimension	C	Novel conjecture; untested
Higgs = mass-conferring spatial structure	B	Consistent with SM; reinterpretation
Dark matter: no particle exists	C	Novel prediction; testable now
Dark energy: relational expansion	B	Alternative to Λ; quantitative test needed
Many Points of View (not MWI)	B	Interpretive; indirect tests possible
Entanglement: null-frame locality	B	Consistent with ER=EPR; mechanism test needed
Cyclical singularity	C	Novel prediction; partially testable
Minimum entropy production rate	C	Novel prediction; testable

2. Tests of Axiom 1: Relational Existence

Axiom 1 states that an entity exists if and only if it interacts with another entity. This has direct physical consequences.

2.1 Test: Isolated Quantum Systems Decohere

PTI prediction: A quantum system that is perfectly isolated from all interactions should not merely be unobservable—it should cease to have definite physical properties. In practice, perfect isolation is impossible, but progressively better isolation should produce progressively less well-defined physical states.

Test: Prepare a quantum system in a superposition and isolate it to varying degrees using electromagnetic shielding, cryogenic cooling, and vacuum. Measure how the system's coherence time scales with the degree of relational isolation. Standard QM predicts coherence time depends only on environmental coupling strength. PTI predicts a potentially different functional form, since the system's very existence (not just its measurability) depends on relational interactions.

Falsification: *If coherence time scales exactly as standard decoherence theory predicts, with no anomalous behavior at extreme isolation, PTI's ontological claim about relational existence (as opposed to standard QM's epistemic interpretation) receives no support.*

Tier: 2 (requires extreme isolation beyond current lab capability)

2.2 Test: Proton Decay (Cyclical Singularity Requirement)

PTI prediction: All massive particles must eventually decay, because the cyclical cosmology requires that all matter convert to radiation. The proton must have a finite lifetime.

Test: Super-Kamiokande has set the current lower bound at $\sim 10^{34}$ years. Hyper-Kamiokande (under construction) will extend this. JUNO and DUNE will also contribute. PTI requires detection of proton decay at some lifetime, or at minimum that no theoretical proof of absolute proton stability emerges.

Falsification: *A rigorous proof that protons cannot decay under any circumstances would falsify the cyclical singularity model. Experimental non-detection only sets a lower bound on cycle time.*

Tier: 1–2 (experiments running and under construction)

3. Tests of Axiom 2: Hierarchical Condensation

3.1 Test: Space Emerges from Entanglement

PTI prediction: Spatial structure is generated by entanglement between temporal/causal relations. Reducing entanglement should reduce spatial connectivity.

Test: This is already supported theoretically by Van Raamsdonk's work and by the Ryu-Takayanagi formula in AdS/CFT. Direct experimental tests would require creating controlled regions of reduced entanglement and measuring spatial properties. Analog experiments in condensed matter systems (e.g., tensor network quantum simulators) can model this: simulate a causal set and measure whether spatial geometry emerges from the entanglement structure of the simulation.

Falsification: *If tensor network simulations definitively show that spatial geometry can exist without entanglement, or that entanglement produces non-spatial structures, the emergence claim is weakened.*

Tier: 1–2 (tensor network simulations feasible now; direct tests require quantum gravity experiments)

3.2 Test: Planck-Scale Discreteness of Gravity

PTI prediction: Gravity arises from discrete relational operations at the Planck scale. The smooth GR description is a statistical average. This predicts Planck-scale noise in gravitational wave signals.

Test 3.2a — Gravitational wave high-frequency noise: Analyze LIGO/Virgo/KAGRA data above 1 kHz for excess noise beyond detector noise and known astrophysical sources. The Einstein Telescope and Cosmic Explorer (next-generation detectors) will have significantly better high-frequency sensitivity. PTI predicts a characteristic noise floor from discrete gravity.

$$S\_PTI(f) \sim (l\_P^2 / t\_P) \times N\_particles$$

Test 3.2b — Holometric experiments: The Fermilab Holometer and proposed successors search for Planck-scale correlations in interferometer signals. PTI predicts correlated jitter at the Planck scale from discrete relational operations.

Falsification: *If gravitational wave signals are perfectly smooth at all accessible frequencies, and holometric experiments detect no Planck-scale correlations even at design sensitivity, the discrete-gravity claim is weakened.*

Tier: 1 (data reanalysis) to 2 (Einstein Telescope, ~2035)

3.3 Test: Three-Dimensionality of Space

PTI prediction: The comparison algebra naturally stabilizes at three independent spatial degrees of freedom. This is currently a claim without rigorous derivation and is one of PTI's open problems.

Test: If the mathematical derivation is completed, it should predict specific consequences for the topology of the early universe (number of large dimensions). This can be compared with CMB observations, which constrain the topology of the observable universe. Additionally, tabletop experiments testing gravity at sub-millimeter distances (Eöt-Wash) constrain extra dimensions.

Falsification: *If the completed PTI derivation predicts a number of spatial dimensions other than 3, or if extra spatial dimensions are discovered at the LHC or in gravity experiments, the specific PTI derivation fails.*

Tier: 1 (Eöt-Wash running) to 3 (depends on mathematical development)

4. Tests of Axiom 3: Frame-Dependent Decomposition

4.1 Test: Unruh Effect Measurement

PTI prediction: Axiom 3 predicts that particle content is frame-dependent, which is the Unruh effect: an accelerated observer sees a thermal bath where an inertial observer sees vacuum. Confirming the Unruh effect confirms Axiom 3's claim about frame-dependent decomposition at the quantum level.

Test: Direct measurement of the Unruh effect requires extreme accelerations (~10^{20} m/s²). Proposed experiments include high-power laser acceleration of electrons (detecting Unruh radiation as modified Larmor radiation) and analog Unruh effects in Bose-Einstein condensates.

Falsification: *If the Unruh effect is definitively shown not to exist (which would also challenge standard QFT), Axiom 3's frame-dependent decomposition at the quantum level is challenged. This is unlikely given QFT's overall success.*

Tier: 2–3 (Unruh effect detection is a major ongoing challenge)

4.2 Test: Bell Tests with Relativistic Frame Differences

PTI prediction: MPV claims measurement outcomes are frame-dependent decompositions. For Bell tests where detectors share the same inertial frame, PTI and standard QM agree. But PTI predicts that when detectors are in significantly different gravitational potentials or relative velocities, the effective "comparison distance" between their reference frames could produce tiny corrections to Bell correlations.

Test: Perform Bell inequality tests with one detector on Earth and one on a satellite (building on the Micius experiment). Compare the measured Bell parameter S against the standard QM prediction $S = 2\sqrt{2} \approx 2.828$. PTI predicts $S = 2\sqrt{2} \times (1 + \varepsilon)$, where ε is a small correction dependent on the gravitational potential difference.

Falsification: *If Bell correlations match standard QM exactly across all reference frame differences, with no frame-dependent corrections, MPV offers no advantage over standard relational QM.*

Tier: 2 (satellite Bell tests in development)

5. Tests of the Gravity Mechanism

5.1 Test: Achromatic Gravitational Lensing (Confirmed)

Status: Already confirmed. Both GR and PTI's river model predict wavelength-independent lensing. This is a Category A test—already confirmed, demonstrates consistency.

Ongoing: JWST and Euclid are measuring lensing at unprecedented precision across wavelengths. Any detection of chromatic lensing would challenge both GR and PTI.

5.2 Test: Zero Photon Vacuum Dispersion

PTI prediction: Photons propagate along null geodesics with no interaction with the spatial manifold's quantum structure. This predicts exactly zero vacuum dispersion—all photon energies travel at exactly c.

Test: Fermi-LAT, MAGIC, H.E.S.S., and the upcoming CTA observe photons from gamma-ray bursts billions of light-years away. If high-energy and low-energy photons arrive simultaneously (correcting for source effects), PTI is supported. Some quantum gravity theories (e.g., loop quantum gravity) predict energy-dependent speed; PTI predicts none.

$$\Delta v/c = 0 \quad \text{(exactly, all energies, all distances)}$$

Falsification: *Detection of vacuum dispersion at any level would falsify PTI's claim that photons do not interact with spatial quantum structure.*

Tier: 1 (data available now from Fermi-LAT; CTA coming ~2027)

5.3 Test: Non-Rotating Black Hole Shadow Asymmetry

PTI prediction: The river model describes spatial flow as radially inward. For a non-rotating (Schwarzschild) black hole, this is perfectly spherically symmetric, producing a perfectly circular shadow—identical to the GR prediction. However, the discrete relational process may introduce tiny fluctuations in the shadow boundary.

Test: Next-generation EHT with space-based baselines will image black hole shadows at much higher resolution. If a non-rotating black hole is identified, its shadow should be perfectly circular in both GR and PTI. Statistical fluctuations at the Planck scale would be far below detection threshold.

Tier: 3 (requires identification of a non-rotating black hole and next-gen EHT)

6. Tests of Dark Matter Prediction

6.1 Test: No Dark Matter Particle Exists

PTI prediction: The gravitational effects attributed to dark matter arise from nonlinear relational dynamics, not from new particles. No dark matter particle of any kind (WIMP, axion, sterile neutrino, etc.) will ever be detected.

Test: XENONnT, LUX-ZEPLIN (LZ), PandaX-4T, and the proposed DARWIN detector are searching with increasing sensitivity. The axion search experiments ADMX and ABRACADABRA cover a different mass range. PTI predicts all will yield null results.

Falsification: *Unambiguous detection of a dark matter particle in any experiment—direct detection, collider production, or indirect detection—would immediately and decisively falsify this prediction. This is PTI's most critical near-term test.*

Tier: 1 (experiments running now)

6.2 Test: Galaxy Rotation Curves from Relational Dynamics

PTI prediction: The "extra gravity" in galaxies arises from the density of relational operations. This should produce a specific functional form for rotation curves that differs from both CDM halo profiles (NFW) and MOND. Deriving this form requires quantitative development of PTI beyond the current qualitative stage.

Test: Once derived, fit the PTI rotation curve prediction against the SPARC database of 175 galaxy rotation curves. Compare χ^2/dof against NFW (CDM), MOND, and Verlinde's emergent gravity predictions.

Falsification: *If the PTI prediction fits significantly worse than CDM or MOND, the relational mechanism is challenged. If it fits comparably or better, it is supported.*

Tier: 1–2 (data exists; requires theoretical development)

6.3 Test: Bullet Cluster Consistency

PTI prediction: The Bullet Cluster, where gravitational lensing mass is separated from visible baryonic mass, is a classic challenge for modified gravity theories. PTI must explain how relational dynamics can produce lensing that tracks the (now-separated) original mass distribution rather than the current baryon distribution. This is an important consistency check.

Falsification: *If PTI cannot produce a quantitative model that explains the Bullet Cluster mass-baryon separation, it faces the same challenge as MOND and other modified gravity approaches.*

Tier: 1–2 (data available; requires theoretical development)

7. Tests of Dark Energy Prediction

7.1 Test: Expansion History and the Hubble Tension

PTI prediction: The expansion rate depends on the balance between relational generation and consumption. As matter dilutes, consumption decreases, and expansion accelerates—potentially with a different time-dependence than the cosmological constant model (ΛCDM), where dark energy density is constant.

Test: DESI (baryon acoustic oscillations), Euclid (weak lensing), and the Nancy Grace Roman Space Telescope (Type Ia SNe) will map the expansion history H(z) with unprecedented precision. PTI predicts H(z) may deviate from ΛCDM, particularly at the transition redshift $z \sim 0.7$ where acceleration began. This could resolve the Hubble tension ($H_0 = 67.4$ vs 73.0 km/s/Mpc) by providing a dynamical dark energy model.

Falsification: *If H(z) matches ΛCDM perfectly at all redshifts, and the Hubble tension is resolved by systematic error rather than new physics, PTI's dynamical dark energy model receives no support (though it is not strictly falsified, since the balance could mimic Λ).*

Tier: 1–2 (DESI first results 2024–2025; Euclid and Roman through 2030s)

8. Tests of Entanglement and Interference

8.1 Test: Entanglement Fidelity Over Extreme Distances

PTI prediction: Entanglement correlations should not degrade with distance in vacuum, because in the null frame there is no distance. Only practical decoherence (interaction with intervening matter) should reduce fidelity.

Test: Extend satellite-based entanglement distribution (building on Micius) to Earth-Moon and eventually Earth-Mars distances. Measure whether the Bell inequality violation parameter S degrades systematically with distance in vacuum after correcting for known loss mechanisms.

Falsification: *Systematic, distance-dependent degradation of entanglement in vacuum (not attributable to known decoherence sources) would challenge the null-frame explanation.*

Tier: 2 (lunar relay missions proposed for 2030s)

8.2 Test: Double-Slit Decoherence Curve

PTI prediction: The transition from interference to no interference as which-path information increases follows a comparison-counting exponential: $V = V_0 \exp(-N\_comp/N\_crit)$. Standard QM predicts $V = V_0\sqrt{(1-D^2)}$ where D is the distinguishability parameter.

$$V\_PTI = V_0 \exp(-N\_comp/N\_crit) \quad vs \quad V\_QM = V_0 \sqrt{(1 - D^2)}$$

Test: Tabletop quantum optics experiment with controlled which-path detector sensitivity. Map the visibility V as a function of detector coupling strength. The two models predict different functional forms that should be distinguishable with sufficiently precise measurements.

Falsification: *If the decoherence curve matches standard QM exactly with no exponential component, PTI's comparison-counting mechanism is falsified.*

Tier: 1 (tabletop optics with current technology)

9. Tests of the Color-Space Correspondence

9.1 Test: Asymmetric Lattice QCD

PTI prediction: If QCD color charges correspond to spatial dimensions, then asymmetric spatial lattices in lattice QCD simulations should produce asymmetric color behavior. Standard QCD predicts that color is a pure internal symmetry, completely decoupled from spatial geometry.

Test: Run lattice QCD simulations with deliberately asymmetric spatial lattice spacings ($a_x \neq a_y \neq a_z$). Measure whether quark propagators, confinement properties, or the hadron spectrum show any dependence on the spatial anisotropy beyond what is expected from standard lattice artifacts. Standard QCD predicts none (after correcting for lattice artifacts). PTI predicts a specific coupling.

Falsification: *If lattice QCD shows absolutely no coupling between spatial geometry and color dynamics on asymmetric lattices (beyond known lattice artifacts), the color-space correspondence is falsified as a physical rather than purely mathematical correspondence.*

Tier: 1 (computational; feasible with existing resources)

9.2 Test: 2D QCD-Like Models

PTI prediction: In a 2D system, only 2 spatial dimensions are available, so PTI predicts that analogous confinement in 2D should require only 2 "colors." Standard SU(3) gauge theory in 2D requires 3 colors regardless of dimensionality.

Test: Study confinement in SU(2) and SU(3) gauge theories in 2+1 dimensions using lattice simulations. If 2-color confinement in 2D is qualitatively similar to 3-color confinement in 3D, it supports the color-dimension mapping. If 3 colors are necessary even in 2D, the mapping is challenged.

Falsification: *If SU(3) confinement in 2D works identically to 3D, with no special status for SU(2), the dimensional correspondence is not supported.*

Tier: 1 (lattice computation; some results already exist)

10. Tests of Cyclical Cosmology

10.1 Test: CMB Anomalies from Previous Cycle

PTI prediction: PTI's cyclical singularity—where a single particle with all the universe's energy decays to restart the cycle—predicts a slight monopole or dipole residual in the CMB from the asymmetry of the initial decay event. This would be a tiny component beneath the known CMB dipole (attributed to Earth's motion).

Test: Reanalyze Planck CMB data after subtracting the kinetic dipole and all known foregrounds. Search for residual anomalies consistent with a single-source origin. Compare with

Penrose's CCC predictions (which predict multiple circular features rather than a single-source signature).

Falsification: *If no residual anomalies exist beyond known sources, and the CMB is perfectly consistent with single-Big-Bang inflation, the cyclical model receives no observational support.*

Tier: 1 (reanalysis of existing Planck data)

10.2 Test: Gravitational Wave Background from Previous Cycle

PTI prediction: If the universe is cyclical, the initial singularity's decay should produce a characteristic gravitational wave background distinct from the inflationary prediction.

Test: LISA (expected launch ~2035) and pulsar timing arrays (NANOGrav, EPTA) will measure the stochastic gravitational wave background. PTI's cyclical model predicts a specific spectral shape that differs from the inflationary prediction.

Tier: 2–3 (LISA launch ~2035; PTA data accumulating)

11. Tests of the Engine of the Present

11.1 Test: Minimum Entropy Production Rate

PTI prediction: Every massive particle performs at least one relational comparison per Planck time, generating at least one new relational result. This predicts a minimum entropy production rate: $dS/dt \geq k_B \times N_{particles} / t_{Planck}$. Standard thermodynamics has no such minimum.

Test: Cool a system to extreme temperatures and measure entropy production with the highest possible precision. If a non-zero entropy floor exists that scales with particle number, PTI is supported.

Falsification: *If entropy production can be reduced arbitrarily close to zero, below the PTI minimum, the relational engine mechanism is falsified.*

Tier: 2–3 (requires precision beyond current cryogenic measurement capability)

12. Summary of All Proposed Tests

Test	PTI Prediction	Category	Tier	Falsified If...
Proton decay	Finite lifetime	C	1–2	Proton proven absolutely stable
Isolated system decoherence	Anomalous behavior at extreme isolation	C	2	Standard decoherence theory exact
GW noise floor	Planck-scale noise in GW signals	C	1–2	GR perfectly smooth at all f
Holometer jitter	Planck-scale correlations	C	1–2	No correlations at design sensitivity
Tensor network emergence	Spatial geometry from entanglement	B	1–2	Geometry without entanglement
Unruh effect	Frame-dependent particle content	A/B	2–3	Unruh effect doesn't exist
Relativistic Bell tests	Tiny frame-dependent corrections to S	C	2	$S = 2\sqrt{2}$ exactly, all frames
GRB vacuum dispersion	Exactly zero dispersion	C	1	Any dispersion detected
DM direct detection	Null result always	C	1	DM particle detected
Rotation curves	PTI-specific functional form	C	1–2	Worse fit than CDM/MOND
Bullet Cluster	Relational model reproduces data	B	1–2	Cannot reproduce separation
H(z) expansion history	Dynamical dark energy	B	1–2	ΛCDM exact at all z
Entanglement over distance	No vacuum degradation	B	2	Distance degradation in vacuum
Double-slit decoherence	Exponential comparison curve	C	1	Standard QM curve exact
Asymmetric lattice QCD	Color-spatial coupling	C	1	No coupling found
2D confinement	2 colors sufficient in 2D	C	1	3 colors needed in 2D
CMB residual anomalies	Single-source residual signature	C	1	No anomalies found
GW background spectrum	Cyclical spectral shape	C	2–3	Matches inflationary prediction
Minimum entropy rate	Non-zero floor at $k_B N/t_P$	C	2–3	Floor absent

13. Conclusion and Recommended Priority

The revised PTI framework clearly distinguishes Category A predictions (already confirmed), Category B predictions (reinterpretations requiring mechanism tests), and Category C predictions (novel, falsifiable). The highest-priority near-term actions are:

First, existing data reanalysis: dark matter null results (Test 6.1), gamma-ray burst dispersion (Test 5.2), CMB anomaly searches (Test 10.1), asymmetric lattice QCD (Test 9.1), and 2D confinement models (Test 9.2). These require no new experiments.

Second, tabletop experiments: double-slit decoherence curve (Test 8.2) is the single most discriminating near-term experiment, as it predicts a specific functional form that differs from standard QM and can be measured with existing optics technology.

Third, the ongoing dark matter detection program: every year of null results from XENONnT, LZ, PandaX, ADMX, and collider searches strengthens PTI. Detection of a dark matter particle would be immediately fatal to this aspect of the theory.

Fourth, theoretical development: the quantitative predictions for galaxy rotation curves, the Bullet Cluster, and the H(z) expansion history require mathematical development of the relational dynamics beyond the current qualitative framework. This theoretical work is essential to convert Category B predictions into Category C (falsifiable) predictions.

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