SPOOKY ACTION, ENTANGLEMENT, AND THE CASE FOR A SECOND TIME DIMENSION

Ninety years of non-local correlations, the no-go theorems that closed every finite-speed escape route, and the theoretical case that the remaining exit runs through a second temporal axis

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EPISTEMIC TAGGING: **[GROUNDED]** established experiment/theory **[ANALYTIC]** valid inference from grounded premises **[PROJECTION]** model-based extrapolation **[SPECULATIVE]** coherent but unverified

0 EXECUTIVE SUMMARY

The claim of this paper, stated plainly: quantum entanglement does not prove a second time dimension exists — but ninety years of experiment have now eliminated every mechanistic explanation of entanglement that lives inside ordinary (3+1)-dimensional spacetime, and a second timelike dimension is one of the few surviving structures in which a causal account of the correlations can still be written down. As of 2025, that survivor has, for the first time, a concrete falsifiable experimental test attached to it. This is a materially different situation than at any prior point in the history of the problem.

Part I *(Sections 1–3)* builds the grounded foundation: the 1935 Einstein–Podolsky–Rosen argument, Bell's 1964 theorem, and the experimental record that closed the locality, detection, and freedom-of-choice loopholes by 2015 and earned the 2022 Nobel Prize. Nature violates Bell inequalities. Local hidden variables are dead. This is settled physics. **[GROUNDED]**

Part II *(Section 4)* identifies the wedge. Two results box in anyone who wants a causal mechanism behind the correlations: the Geneva group's 2008 measurement forcing any hypothetical 'influence' between entangled particles to travel at no less than ~10,000c, and the 2012 Bancal et al. no-go theorem proving that any finite-speed influence — however fast — would permit genuine faster-than-light signaling, which nothing in nature does. The mechanism must therefore be infinitely fast in every reference frame, which is another way of saying it cannot propagate through ordinary spacetime at all. Either there is no mechanism (the mainstream position), or the mechanism propagates through structure that (3+1) spacetime does not contain. **[ANALYTIC]**

Part III *(Sections 5–7)* develops the second-time thesis in three layers: (i) the theoretical infrastructure — Itzhak Bars' two-time physics, in which a (4+2)-dimensional spacetime with Sp(2,R) gauge symmetry reproduces ordinary one-time physics as gauge-fixed 'shadows' while curing the ghost and instability pathologies that generically kill extra-time proposals; (ii) the direct argument — Marco Pettini's 2025 model (Physical Review Research 7, 013261), developed in dialogue with Roger Penrose, in which wavefunction collapse propagates at finite speed through a second temporal dimension and therefore appears instantaneous in ours, with a specific four-observer photonic experiment whose anomalous cross-source correlations would be the smoking gun; and (iii) the circumstantial record, including the 2022 trapped-ion demonstration that a synthetic second time dimension is not merely consistent but functional — quasiperiodic Fibonacci driving mathematically equivalent to evolution in two temporal directions produced a dynamical topological phase that protected quantum information far longer than any one-time drive. **[SPECULATIVE]**

Verdict *(Section 8)* runs three scenarios. The base case remains that entanglement correlations are primitive and need no carrier — the position of most working physicists. But the thesis scenario is no longer unfalsifiable philosophy: it makes a laboratory prediction that standard quantum mechanics forbids, and the experiment is within reach of existing photonics. Papers that convert metaphysics into an experimental discriminator are how this subject has advanced every single time — EPR to Bell to Aspect to Delft. The honest posture is not belief; it is watching the test.

1935 → 2015	2√2 ≈ 2.828	≥ 10,000 c	1
YEARS FROM EPR PARADOX TO LOOPHOLE-FREE BELL TESTS	TSIRELSON BOUND — QUANTUM CEILING, CONFIRMED	EXPERIMENTAL FLOOR ON ANY 'INFLUENCE' SPEED (GENEVA 2008)	FALSIFIABLE 2-TIME COLLAPSE TEST ON THE TABLE (PETTINI 2025)

1 THE EPR ARGUMENT AND THE ORIGIN OF 'SPOOKY ACTION'

1.1 What Einstein actually claimed [GROUNDED]

In May 1935, Einstein, Podolsky, and Rosen published 'Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?' (Physical Review 47, 777). The paper is routinely misremembered as an attack on quantum mechanics' predictions. It was not. EPR accepted every prediction of the theory; their target was its *completeness* — whether the wavefunction is the whole story about a physical system, or a statistical summary of something deeper.

The argument rests on two premises. First, a criterion of reality: if, without in any way disturbing a system, one can predict with certainty the value of a physical quantity, then there exists an element of physical reality corresponding to that quantity. Second, locality: what happens at one location cannot instantaneously influence the real state of affairs at a distant location. Neither premise struck anyone in 1935 as exotic. Both are how classical physics — and everyday reasoning — work.

EPR constructed a two-particle state in which measuring the position of particle A lets one predict the position of distant particle B with certainty, while measuring A's momentum instead lets one predict B's momentum with certainty. By the reality criterion, B possesses definite values for both quantities — since either could have been predicted without touching B. But quantum mechanics assigns no state in which position and momentum are simultaneously sharp. Therefore, EPR concluded, the quantum description is incomplete: there must be additional variables — later called *hidden variables* — that quantum mechanics omits.

The phrase itself came later. In a 3 March 1947 letter to Max Born, Einstein wrote that he could not accept quantum mechanics as complete because the theory seemed to entail *spukhafte Fernwirkung* — spooky action at a distance. The alternative he preferred all his life was that the correlations were fixed at the source, like a pair of gloves separated into two boxes: open one box, find a left glove, and you know instantly the other box holds a right glove. Nothing spooky — the gloves were always what they were. The entire subsequent history of the subject is the discovery, by theorem and then by experiment, that nature refuses the glove story. [GROUNDED]

1.2 Bohm's sharpening: the singlet state [GROUNDED]

David Bohm's 1951 reformulation replaced continuous position/momentum with discrete spin, which is where every modern treatment begins. Two spin-1/2 particles are prepared in the singlet state:

$$|\psi^-\rangle = (1/\sqrt{2})\,(\,|\uparrow\rangle_a|\downarrow\rangle_\beta - |\downarrow\rangle_a|\uparrow\rangle_\beta\,) \quad (1)$$

This state has three properties that carry all the weight in what follows. First, it is *rotationally invariant*: it has the same form regardless of which spatial axis defines 'up.' Second, neither particle individually has any definite spin — each particle's reduced state is maximally mixed, an unpolarized coin. Third, the two outcomes are perfectly anticorrelated along any common axis: if Alice measures spin along direction â and gets +1, Bob measuring along â gets −1, always, at any separation. For measurements along different axes â and $\hat{b}$ separated by angle θ, quantum mechanics predicts the correlation function

$$E(\hat{a}, \hat{b}) = \langle(\sigma\cdot\hat{a}) \otimes (\sigma\cdot\hat{b})\rangle = -\,\hat{a}\cdot\hat{b} = -\cos\theta \quad (2)$$

Equation (2) is the entire experimental content of the dispute. A local hidden variable theory must reproduce it to survive. Bell's discovery was that it cannot.

2 BELL'S THEOREM AND THE EXPERIMENTAL VERDICT

2.1 The theorem [GROUNDED]

John Stewart Bell's 1964 paper ('On the Einstein Podolsky Rosen Paradox,' Physics 1, 195) converted a seventy-year philosophical argument into an inequality a laboratory can test — arguably the highest ratio of consequence to length in the history of physics. Bell formalized what any local hidden variable theory must look like. Let λ denote the complete hidden state of the pair, distributed with density ρ(λ), fixed at the source. Locality requires that Alice's outcome depend only on her setting and λ, and Bob's only on his setting and λ:

$$E(\hat{a}, \hat{b}) = \int d\lambda\, \rho(\lambda)\, A(\hat{a}, \lambda)\, B(\hat{b}, \lambda), \quad \text{with } A, B \in \{+1, -1\} \quad (3)$$

The critical structural point: in (3), the settings â and $\hat{b}$ enter *factorized* — Alice's function A never sees Bob's setting, and vice versa. That factorization is locality, rendered in mathematics. Everything else about λ is unrestricted: it may be a single number, an infinite field, deterministic or stochastic. Bell showed that no distribution ρ and no response functions A, B satisfying (3) can reproduce equation (2) for all angle choices. The 1969 Clauser–Horne–Shimony–Holt (CHSH) form is the operational version. For two settings per side (â, â′ for Alice; $\hat{b}$, $\hat{b}'$ for Bob), define

$$S = E(\hat{a},\hat{b}) - E(\hat{a},\hat{b}') + E(\hat{a}',\hat{b}) + E(\hat{a}',\hat{b}') \quad (4)$$

Every theory of the form (3) obeys $|S| \le 2$. The proof is three lines: for fixed λ, $B(\hat{b},\lambda) + B(\hat{b}',\lambda)$ and $B(\hat{b},\lambda) - B(\hat{b}',\lambda)$ are ±2 and 0 in some order, so the integrand is bounded by 2 in magnitude, and averaging cannot exceed the bound. Quantum mechanics, using (2) with coplanar settings at 0°, 90° (Alice) and 45°, 135° (Bob), yields $|S| = 2\sqrt{2} \approx 2.828$ — a 41% violation. The $2\sqrt{2}$ ceiling is itself a

theorem (Tsirelson, 1980): no quantum state and no measurements can exceed it. Nature, wherever tested, saturates the quantum value and never passes it. [GROUNDED]

Read carefully what the theorem does and does not say. It does not say quantum mechanics is nonlocal in the sense of transmitting signals. It says: the experimentally observed correlations *cannot be produced by any mechanism* in which outcomes are determined by locally-carried information fixed at the source. The glove story is mathematically excluded — not implausible, not disfavored: excluded.

2.2 Sixty years of experiment: closing every loophole [GROUNDED]

A Bell violation only kills local realism if the experiment forecloses every classical side-channel. Three loopholes dominated the program: locality (could a light-speed signal have carried one side's setting to the other before its measurement finished?), detection (are detected pairs an unrepresentative 'fair sample'?), and freedom-of-choice (could the settings share a common past cause with the hidden variables?). The record:

YEAR	EXPERIMENT	WHAT IT ESTABLISHED
1972	Freedman & Clauser (Berkeley)	First CHSH-type violation, entangled photons from a calcium cascade. Loopholes open, result unambiguous in direction.
1981–82	Aspect et al. (Orsay)	Violation with time-varying analyzers switched in flight — first serious attack on the locality loophole. S measured within 1% of quantum prediction.
1998	Weihs et al. (Innsbruck)	Strict Einstein locality: fast quantum random number generators chose settings after photon emission, 400 m separation, spacelike-separated measurement events.
2001	Rowe et al. (NIST)	Detection loophole closed with trapped ions — near-unit detection efficiency, though ions were microns apart (locality open).
2015	Hensen et al. (Delft); Giustina et al. (Vienna); Shalm et al. (NIST)	Loophole-free, all three groups within months. Delft: electron spins in diamond NV centers 1.3 km apart, event-ready entanglement swapping, locality and detection closed simultaneously. Photonic experiments: >75% system efficiency superconducting detectors.
2017–18	Cosmic Bell tests (Handsteiner; Rauch et al.)	Settings derived from starlight and then quasar light emitted ~7.8 billion years ago — any common-cause conspiracy must predate most of cosmic history.
2022	Nobel Prize: Aspect, Clauser, Zeilinger	Institutional closure: Bell violation is now textbook fact, not open controversy.

The 2015 trio deserves emphasis because of what 'loophole-free' means logically. The Delft experiment's two measurement events were spacelike separated: no signal at or below light speed could connect the choice of setting on one side to the outcome on the other. Detection efficiency was high enough that no fair-sampling assumption was needed. The violation persisted ($S = 2.42 \pm 0.20$ at Delft; the photonic experiments rejected local realism at p-values below 10^{-30}). There is no remaining classical account except superdeterminism — the position that the experimenters' choices themselves were correlated with the particles by initial conditions of the universe, which saves locality

at the price of abandoning the independence assumptions on which all empirical science rests. We set it aside, as does essentially the entire field. [GROUNDED]

3 WHAT ENTANGLEMENT DOES — AND STRICTLY DOES NOT — PERMIT

3.1 The no-signaling theorem [GROUNDED]

The single most-abused fact in popular treatments: entanglement cannot transmit information. This is a theorem, not an engineering limitation. Bob's local statistics — the reduced density matrix $\rho_\beta = \mathrm{Tr}_a(\rho_{a\beta})$ — are mathematically independent of which measurement Alice performs, or whether she measures at all. Whatever Alice does, Bob sees an unpolarized coin. The correlations only become visible when the two datasets are brought together and compared, and that comparison travels by classical channel at ≤ c. Quantum mechanics is therefore in 'peaceful coexistence' (Shimony's phrase) with special relativity at the operational level: no causal paradoxes, no ansible, no faster-than-light telegraph. Every scheme ever proposed to signal through entanglement dies on this theorem, and the theorem is as solid as linearity and the tensor-product structure of quantum mechanics itself.

3.2 The structure of the correlations [GROUNDED]

Three structural facts sharpen what any deeper theory must explain. First, *Tsirelson's bound*: quantum correlations reach $2\sqrt{2}$ but stop there, even though the no-signaling principle alone would permit S = 4 (the Popescu–Rohrlich box). Nature is nonlocal, but not maximally nonlocal — the specific quantum ceiling is a clue, not an accident, and any mechanism proposed for entanglement must reproduce exactly it. Second, *monogamy*: if A is maximally entangled with B, it cannot be entangled with C at all. Entanglement behaves like a conserved, exclusive resource — again a strong structural constraint on any underlying account. Third, *entanglement swapping*: two particles that have never interacted, never coexisted in a common light cone, can be entangled by a joint measurement on their partners. Whatever picture one holds of a 'link' between entangled particles, that link can be created between systems with no shared causal past — which strains any mechanism that lives in ordinary spacetime history. [GROUNDED]

3.3 So what is 'spooky' exactly? [ANALYTIC]

Assemble the pieces. The outcomes are individually random (no-signaling requires it). The outcomes are jointly correlated beyond any local common-cause explanation (Bell requires it). And the correlations arise regardless of spatial separation, with no attenuation, no delay, and no medium. What is spooky is not action — nothing measurable is transmitted — but the existence of a *global constraint on random events at spacelike separation*. Two dice, light-years apart, each perfectly fair, that nevertheless always land opposite. Standard quantum mechanics offers the joint wavefunction as a complete description of this and declines to say more. The question that motivates Part III is whether 'declines to say more' is wisdom or an armistice.

4 THE RELATIVISTIC WEDGE: WHY (3+1) SPACETIME HAS NO ROOM FOR A MECHANISM

4.1 Collapse and the relativity of simultaneity [ANALYTIC]

Suppose one insists — with Einstein, Bohm, Bell, and Penrose — that the correlations deserve a causal account: that when Alice measures, something *happens* that fixes Bob's outcome. Immediately relativity objects. For spacelike-separated measurements, the time ordering of Alice's and Bob's events is frame-dependent: in some inertial frames Alice measured first, in others Bob did. A dynamical collapse propagating from 'first' measurement to 'second' requires a fact about which came first — a preferred foliation of spacetime into instants — that special relativity says does not exist. Every realist mechanism thus begins its life in tension with the geometry it must live in. Bohmian mechanics accepts this openly: it requires a preferred frame, empirically hidden but ontologically real. The question is whether the mechanism can be quantified and cornered experimentally. It can, and it was.

4.2 The Geneva bound: influence at ≥ 10,000c [GROUNDED]

Salart et al. (Nature 454, 861, 2008) ran entangled photons to two villages 18 km apart, east and west of Geneva, with measurements timed to be as simultaneous as possible, and kept the violation running continuously for 24 hours as the Earth rotated the apparatus through every orientation relative to any hypothetical preferred frame. If wavefunction collapse were an influence propagating at some finite speed v in a preferred frame, there would exist orientations and timings for which the influence arrives too late and the correlations degrade. They never degraded. The bound: in any preferred frame moving at less than 10^{-3} c relative to Earth, the 'speed of spooky action' exceeds 10,000 times the speed of light. Later refinements pushed the bound higher. This is a measured, published floor under any finite-speed mechanism. [GROUNDED]

4.3 The Bancal no-go: finite speed at any value is dead [GROUNDED]

One could still imagine v = 10^6c, or 10^9c. Bancal, Pironio, Acín, Scarani, Gisin, and colleagues closed that road in 2012 (Nature Physics 8, 867: 'Quantum non-locality based on finite-speed causal influences leads to superluminal signaling'). The theorem: take any model in which correlations are established by causal influences propagating at finite speed v, with $c < v < \infty$, in some preferred frame. For bipartite experiments such a model can always hide — arrange the measurements close enough to simultaneity and the influence always arrives. But for four parties, the theorem shows the model necessarily predicts correlations that would allow genuine superluminal *signaling* at the operational level — actual usable faster-than-light communication between experimenters. Since no-signaling is among the best-tested facts in physics, every finite-v model is excluded, for every finite v. The options that remain:

1. **No mechanism.** The correlations are primitive facts about nature; the joint quantum state is the complete story; asking 'how does Bob's particle know' is a category error. This is the working position of most physicists and of the Everett, QBist, and relational interpretations, where there is no collapse to propagate in the first place.

2. **Infinite-speed influence in a preferred frame.** Bohmian mechanics' position. Consistent, but 'infinite speed in a preferred foliation' is a mechanism that does no propagating — it is instantaneous coordination wearing a mechanism's clothes, and the preferred frame is forever unobservable in principle.
3. **A mechanism propagating outside (3+1) spacetime.** The influence travels at finite — even subluminal — speed, but along a dimension orthogonal to ordinary time, re-entering our spacetime at the distant measurement event with zero elapsed ordinary time. Instantaneity in t becomes an artifact of projection, exactly as a 3D object passing through a 2D plane produces 'impossible' simultaneous appearances to Flatlanders.

Option 3 is the doorway to the second time dimension. Note the logical form of the claim before proceeding: the no-go theorems do not support option 3 over option 1. They establish that *if* one demands a causal mechanism at all, options inside ordinary spacetime are exhausted. The 'evidence' for a second time dimension is, at this stage, the evidence of an eliminated field of competitors — circumstantial, in the way that a locked room points to the one unlocked window. Part III examines whether the window actually opens. [ANALYTIC]

5 TWO-TIME PHYSICS: THE THEORETICAL INFRASTRUCTURE

5.1 Why extra time is usually fatal — the pathology list [GROUNDED]

Any proposal for a second timelike dimension must first survive four classic executioners, each independently lethal. Honest accounting requires stating them at full strength.

- **Ghosts and unitarity.** In field theory, oscillator modes along a timelike direction quantize with negative-norm states ('ghosts'). Negative norms make probabilities negative and destroy unitarity — the theory stops conserving probability, which is not a blemish but a death.
- **Ill-posedness.** With two times, wave equations become ultrahyperbolic. Max Tegmark's 1997 analysis ('On the dimensionality of spacetime,' Classical and Quantum Gravity 14, L69) showed that ultrahyperbolic equations admit no well-posed initial value problem: finite data on a spacelike surface does not determine the future. A universe with two full-strength times is a universe in which physics cannot predict — and in which observers of our kind arguably cannot exist. This is the strongest single argument that we observe (3+1) because only (3+1) permits stable, predictive physics.
- **Closed timelike curves.** A compact or navigable extra time invites trajectories that loop in time — grandfather paradoxes as dynamics. This was precisely Penrose's stated objection when Pettini raised the idea with him (Section 6.2).
- **Tachyonic instabilities.** Kaluza–Klein reduction along a timelike circle generically produces towers of tachyonic modes: the vacuum itself decays.

The pathology list is why 'add another time' is not a move available to amateurs. It is also why the surviving frameworks are interesting: each survives by adding a *principle* — a symmetry or a

confinement mechanism — that surgically removes the diseases while keeping the extra dimension. The pattern of what must be added is itself informative. [ANALYTIC]

5.2 Bars' 2T-physics: gauge symmetry as the cure [GROUNDED]

The most developed framework is Itzhak Bars' two-time physics (USC, 1998–present). The starting observation: classical mechanics treats position X and momentum P asymmetrically, but nothing in the deep structure requires it. Demand instead a local Sp(2,R) gauge symmetry — invariance under position–momentum rotations performed independently at each instant. Consistency of this demand forces two remarkable conclusions. First, the symmetry cannot be implemented nontrivially in a spacetime with one time: it *requires exactly two* timelike dimensions — one is too few for nontrivial content, three or more reintroduce ghosts. Second, the same gauge symmetry that demands the second time also removes every negative-norm state: the constraints $X \cdot X = 0$, $X \cdot P = 0$, $P \cdot P = 0$ (in the SO(d,2) metric) precisely eliminate the ghost sector. The disease and the cure arrive as a package.

The physical payoff is the 'shadow' structure. A single (4+2)-dimensional system, gauge-fixed in different ways, projects onto multiple inequivalent (3+1)-dimensional systems: the free relativistic particle, the hydrogen atom, the harmonic oscillator, particles in specific curved backgrounds — systems that look unrelated in one-time physics are revealed as different perspectives on one higher system, related by hidden symmetries. The long-mysterious SO(4,2) conformal symmetry of the massless particle and of the hydrogen spectrum, known since the 1930s, falls out naturally: it is the rotation group of a (4+2) spacetime, visible in the shadow as an unexplained 'accidental' symmetry. Bars subsequently reformulated the complete Standard Model and gravity in 4+2 dimensions, with claimed shadow-level consequences including a resolution of the strong CP problem without an axion. Independently, Cumrun Vafa's F-theory (1996) organizes string dualities in twelve dimensions with signature (10,2) — a second timelike direction appearing at the summit of the duality web, albeit not fully dynamical. [GROUNDED]

The epistemic status must be stated precisely. 2T-physics is mathematically consistent, reproduces all tested physics, and explains otherwise-unexplained symmetry patterns. What it does not yet have is a confirmed prediction that one-time physics cannot match. It establishes possibility and fruitfulness, not existence. In the language of this paper's tagging: the framework is GROUNDED as mathematics, ANALYTIC as physics, and its ontic reading — that the second time is out there — is PROJECTION. [ANALYTIC]

5.3 Imaginary time: the second time already in the toolbox [GROUNDED]

A further piece of circumstantial infrastructure: physics already uses a second time direction daily, under the name of Wick rotation. Quantum field theory computations rotate $t \to -i\tau$, work in Euclidean signature where the mathematics is convergent, and rotate back. Finite-temperature field theory identifies inverse temperature with periodic imaginary time. The Hartle–Hawking no-boundary proposal takes imaginary time ontologically seriously near the Big Bang, where the distinction between time and space dissolves. In every case the official position is that τ is 'a calculational device' — yet it is a device that keeps producing correct physics, including tunneling rates and black hole thermodynamics, that are hard to obtain any other way. A pattern in which a hidden

structure is repeatedly needed for the answers but denied a place in the ontology is, historically, the pattern that preceded atoms, quanta, and quarks. It proves nothing; it rhymes.

6 THE THESIS: ENTANGLEMENT AS EVIDENCE FOR A SECOND TIME DIMENSION

6.1 The argument in premises [ANALYTIC]

Stated as a numbered chain, with each link tagged:

4. Nature violates Bell inequalities with spacelike separation; local hidden variables are excluded. [GROUNDED]
5. Any causal mechanism establishing the correlations at finite speed v, for any finite $v > c$, implies operational superluminal signaling (Bancal 2012), which is excluded by experiment. [GROUNDED]
6. Therefore a causal mechanism, if one exists, cannot propagate within (3+1) spacetime: it must be instantaneous-in-every-frame, i.e., effectively outside ordinary time. [ANALYTIC]
7. A second timelike dimension provides exactly this: a finite-speed process in t_2 projects onto zero elapsed t_1, making apparent instantaneity an artifact of dimensional shadow rather than a violation of causality. [ANALYTIC]
8. Consistent two-time frameworks exist in which the standard pathologies are cured (Bars) and in which massive particles are confined off the second time, hiding it from direct observation while leaving it available to wavefunction dynamics (the metric-confinement mechanism invoked by Pettini). [GROUNDED] as mathematics
9. Conclusion: entanglement phenomenology is precisely what a (3+2)-dimensional world with confined second time would look like from inside its (3+1) shadow — and the hypothesis now makes at least one laboratory prediction that standard quantum mechanics does not. [SPECULATIVE]

The word 'evidence' is thus used here in its inferential sense: the observed structure of the correlations (perfect, unattenuated, instantaneous-in-all-frames, yet non-signaling) is *more probable under* the two-time hypothesis than under generic alternatives that posit mechanisms — because every in-spacetime mechanism is dead by theorem, while the two-time mechanism survives with its natural predictions intact. Against the no-mechanism null hypothesis, the evidence is currently neutral; Sections 6.2–6.4 are about the experiment designed to break that tie.

6.2 Pettini 2025: a concrete two-time collapse model with a test [GROUNDED]

In February 2025, Marco Pettini (Aix-Marseille) published 'Quantum entanglement and the geometry of spacetime with two temporal dimensions' as a Physical Review Research article (7, 013261). The provenance matters: Pettini reports the idea arose in conversations with Roger Penrose, who regards entanglement as the deepest open mystery in physics, and the model deliberately extends the nonlocal hidden variable program of Bohm and Bub — the one realist lineage the no-go theorems left breathing. The construction: particle wavefunctions are five-dimensional (three space, two time). Measurement collapse is a genuine dynamical process, but it propagates through the second temporal dimension t_2.

Projected into ordinary time t_1, the collapse front connects Alice's and Bob's measurement events with zero elapsed t_1 — apparent instantaneity, actual finite-speed local dynamics one dimension up. [GROUNDED] (that the model exists and is published; its truth is SPECULATIVE)

Penrose's objection — that a navigable extra time permits causal loops and ancestor paradoxes — is answered by the confinement mechanism: a modification of the enlarged spacetime metric under which massive particles are dynamically confined with respect to t_2. Beings made of massive particles neither travel nor see along the second time; only the wavefunction's collapse dynamics uses it. This is the timelike analogue of brane-world confinement in extra spatial dimensions, and it simultaneously addresses the Tegmark ill-posedness concern: predictive (3+1) physics is preserved for everything made of matter, because matter is pinned to a single-time slice. [ANALYTIC]

6.3 The smoking-gun experiment [PROJECTION]

The model's decisive feature is that it predicts something standard quantum mechanics forbids. The proposed configuration:

- Two independent sources each emit polarization-entangled photon pairs, simultaneously. Source 1 sends its pair to Alice and Bob; source 2 sends its pair to Eve and Tom. Identical detectors throughout.
- Geometry is the active ingredient: Alice and Eve are stationed close together and close to the sources; Bob and Tom are far away. Standard quantum mechanics is emphatic about this arrangement: Alice–Bob are entangled, Eve–Tom are entangled, and Alice–Eve share nothing — their photons come from independent sources with no joint state and no interaction.
- The two-time prediction: when Alice's measurement collapses her pair's wavefunction, the collapse front propagating through t_2 toward Bob passes, in the enlarged geometry, near Eve's nearby identical photon — and couples to it. Ditto Eve's collapse and Alice. The result is anomalous Alice–Eve correlations: interference effects and Bell-type inequality violations between photons that standard quantum mechanics says are strictly unentangled. In Pettini's words, Alice and Eve would influence each other as if entangled — the smoking gun.

This is a real discriminator, and both outcomes are informative. A confirmed anomalous correlation, replicated and loophole-checked, would be the first direct empirical evidence for structure beyond (3+1) spacetime — discovery-of-the-century material. A clean null result kills this particular model (though not the two-time idea in its Bars form, which predicts no such coupling) and further entrenches the no-mechanism position. The experiment requires two entangled-photon sources, fast coincidence electronics, and careful geometry — demanding but within the reach of existing quantum optics laboratories; it is the kind of tabletop-scale test that settled the Bell question itself. For completeness: skepticism from within the hidden-variable lineage is on record. Jeffrey Bub — whose 1966 work with Bohm the model builds on — calls the cross-photon coupling 'a big leap' and expects nothing to come of it, adding that he no longer regards collapse as a dynamical process at all. That is the null hypothesis speaking, and it may well be right. But it is now a bet with a settlement mechanism, which is more than the field has had since 1935. [PROJECTION]

6.4 The synthetic second time: the 2022 trapped-ion result [GROUNDED]

One laboratory result belongs in the evidence file, provided it is filed honestly. In 2022, Dumitrescu, Potter, and collaborators (Nature 607, 463) drove a ten-qubit trapped-ion processor ($^{171}Yb^{+}$, Quantinuum H1) with laser pulses sequenced in the quasiperiodic Fibonacci pattern rather than a periodic rhythm. A quasiperiodic drive built from two incommensurate frequencies is mathematically equivalent to a periodic drive in *two time dimensions*: the system's dynamics live on a two-torus in time, and the drive inherits the topology of that higher-dimensional temporal structure. The payoff was not cosmetic. The two-time topology stabilized a dynamical topological phase whose edge qubits were protected against decoherence for the full duration of the experiment (~5.5 seconds), where the equivalent periodic (one-time) drive lost coherence within ~1.5 seconds. The extra temporal dimension, though synthetic, did real physical work — it protected quantum information via a topological mechanism that has no one-time counterpart.

What this does and does not establish. It does not show that spacetime has a second time; the second dimension here is emergent in the drive's frequency structure, not a direction anything travels. What it establishes is narrower but real: two-time dynamical structure is internally consistent, physically realizable, experimentally controllable, and functionally advantageous for quantum coherence — the very quantity at stake in entanglement. The pathology list of Section 5.1 predicted that two-time dynamics should be unstable nonsense; a two-time-structured quantum system instead proved more stable than its one-time competitor. As circumstantial evidence goes, a demonstration that the suspect's alibi ('two times cannot even work in principle') is false has genuine weight. [ANALYTIC]

7 COUNTERARGUMENTS AT FULL STRENGTH

A thesis worth holding is worth attacking properly. The strongest objections, in descending order of force:

- **There is nothing to explain.** The mainstream position: no-signaling means no action occurs, so no mechanism is needed; correlations without causation are simply what the quantum state describes ('passion at a distance,' in Shimony's phrase). In Everettian, relational, and QBist interpretations there is no collapse event to propagate anywhere, in any number of time dimensions — the entire motivating problem dissolves. The two-time thesis is thus hostage to a specific interpretive commitment: that collapse is a real dynamical process. That commitment is respectable (Penrose holds it) but minority.
- **Occam.** Standard quantum mechanics predicts every observed correlation with zero extra dimensions. A new dimension of time, plus a confinement mechanism, plus a collapse dynamics, is a great deal of ontology purchased to explain phenomena already predicted exactly. The reply — that prediction is not explanation — is philosophy until Section 6.3's experiment says otherwise.
- **The pathologies may be dodged, not solved.** Bars' cure works within his gauge framework; Pettini's confinement is a model assumption. Whether a full interacting quantum field theory with gravity survives on (3+2) with all four executioners held off remains unproven. Tegmark's

predictability argument still stands as an anthropic boundary: whatever the second time does, it must do it without ever un-pinning matter.

- **No independent signature.** No Kaluza–Klein towers, no collider anomalies, no cosmological imprint has ever pointed at extra time. Extra-dimension searches at the LHC constrain spatial proposals; a confined timelike dimension is designed to be invisible, which is either elegant or convenient depending on one's mood. Unfalsifiability-by-design is the historical graveyard of such ideas — which is exactly why the Pettini prediction, the one place the design leaks, carries the whole evidentiary burden.
- **The synthetic result cuts both ways.** A skeptic reads the 2022 ion experiment as showing two-time structure is a useful mathematical coordinate — like imaginary time — with no ontic commitment required. Correct. The rebuttal is only that 'useful, consistent, and repeatedly load-bearing' is how real structures historically announced themselves before direct detection.

8 VERDICT: THREE SCENARIOS

CASE	CORE CLAIM	STATUS	DISCRIMINATING TEST	ASSESSMENT
A — Ontic second time	A (3+2) spacetime with matter confined off t_2; collapse is dynamical and propagates in t_2; entanglement's instantaneity is projection.	SPECULATIVE	Pettini four-observer photonic test shows anomalous Alice–Eve correlations forbidden by standard QM; replication across geometries.	Low prior, revolutionary payoff. The only scenario with a near-term positive signature. A confirmed anomaly would be the largest single discovery since quantum mechanics itself.
B — Structural second time	Two-time physics (Bars) is the correct organizing structure — the second time is real as gauge-level geometry, but no collapse propagates through it and no cross-source coupling exists.	ANALYTIC / PROJECTION	A confirmed shadow-level prediction unique to 4+2 (e.g., strong-CP resolution without an axion; specific dark-matter or cosmological signatures under investigation in the 2T program).	Moderate plausibility. Explains the 'accidental' SO(4,2) symmetries and unifies the duality web; predicts a null result in the Pettini test. Progress will be slow and theoretical.
C — No second time (base case)	Correlations are primitive; the quantum state is complete; instantaneity is a pseudo-problem created by demanding mechanisms where none exist.	GROUNDED-consistent	Pettini test returns null; Tsirelson bound continues to hold in all regimes; no anomaly accumulates across decades of quantum-network operation.	The default of the field and the smart-money position. Its cost is permanent: physics keeps the correlations and abandons the question of why they are there.

Bottom line. Entanglement is not proof of a second time dimension, and this paper has not pretended otherwise. What entanglement provides is a precisely shaped hole: ninety years of theorem and experiment have established that if a mechanism exists, it cannot live in the spacetime we see — and a confined second temporal dimension is the most developed structure that fits the hole, cures its own classical pathologies, has a working synthetic demonstration of its dynamical consistency, and, as of 2025, stakes a falsifiable laboratory claim. Scenario C remains the base case at perhaps 80–90% weight. But the field has moved from 'unanswerable' to 'testable,' and every prior time this subject crossed that line — 1964, 1972, 2015 — the test got run and the universe answered. Watch for the four-observer experiment. Either outcome will be worth more than the entire preceding decade of argument. [ANALYTIC]

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— End of working paper. Prepared by Kevin Nussbaum / Applied Futures Research, August 2026. Epistemic tags are load-bearing: nothing marked SPECULATIVE should be quoted as established.