
Crystallography of the Atom in the TCGS-SEQUENTION Framework: Wavefunctions, Neutrinos, and Nuclear Knots

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Article

Crystallography of the Atom in the TCGS-SEQUENTION Framework: Wavefunctions, Neutrinos, and Nuclear Knots

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Abstract

The Timeless Counterspace & Shadow Gravity (TCGS) framework postulates that the observable three-dimensional (3-D) universe is a shadow manifold Σ embedded in a four-dimensional (4-D) Counterspace $(\mathcal{C}, G_{AB}, \Psi)$ that contains the full content of all apparent “time stages”. In previous work, this ontology was applied to cosmology and biological evolution (SEQUENTION), and later extended to a geometric description of atomic orbitals as “electronic filaments” anchored to a single singular origin $p_0 \in \mathcal{C}$. The present manuscript consolidates that atomic programme in light of three recent classes of empirical evidence: (i) the experimental demonstration of the Pusey–Barrett–Rudolph (PBR) theorem on superconducting processors, (ii) the first observation of solar neutrino charged-current interactions on ^{13}C in SNO+, and (iii) the ALICE Collaboration’s tomographic reconstruction of deuteron formation from short-lived Δ resonances in high-energy proton–proton collisions. We show that these results jointly provide an “ontological license” to abandon purely probabilistic atoms. The PBR test rules out ψ -epistemic models and—when reinterpreted cartographically—forces hidden variables to reside in the 4-D bulk rather than in the 3-D shadow. Within TCGS, the quantum state is redefined as a tomographic map of a rigid 4-D filament, not a standalone 3-D object. The SNO+ data clarifies the role of neutrinos: rather than passive agents in a collapse process, they act as *topological torsion operators* that perform geometric surgery on nuclear knots, pushing stable isotopes into metastable corridors in Counterspace. The ALICE analysis then reveals that stable light nuclei (deuterons) are crystallized products of specific resonance ancestries, confirming that nuclear stability is a property of projection geometry and knot ancestry, not of pointlike constituents. On this basis we construct a unified “Crystallography of the Atom” in which: (1) the wavefunction is a 3-D tomogram of a 4-D isopotential filament; (2) the nucleus is a geometric knot with isotope-dependent docking admissibility; (3) neutrinos carry quantized torsion that re-anchors the singular set $S \subset \mathcal{C}$; and (4) half-lives and delays are reinterpreted as arc lengths along metastable corridors in the foliation parameter. The framework preserves all standard quantum predictions but replaces ontic probabilities with geometric rigidity and corridor depth. We outline empirical tests—from modified PBR experiments to neutrino interactions on additional isotopes—that can discriminate this geometric atom from conventional probabilistic interpretations.

Keywords: TCGS-SEQUENTION; Timeless Counterspace; Shadow Gravity; gravito-capillary foam; geometric atom; metacrystals; isopotential pinches; electronic filaments; wavefunction tomography; ψ -ontic models; PBR theorem; superconducting qubits; hidden variables in 4-D bulk; nuclear crystallography; nuclear knots; resonance ancestry; deuteron formation; ALICE Collaboration; solar neutrinos; SNO+ Collaboration; topological torsion operators; neutrino-induced transmutation; projection geometry; foliation corridors; extrinsic constitutive law; orbital torsion modes; magnetic orbitals

1. Introduction: From Probabilistic Atoms to Geometric Filaments

Standard quantum mechanics describes atomic electrons by a complex-valued wavefunction $\psi(x)$ whose squared modulus $|\psi|^2$ is interpreted as a probability density for finding the electron at position

x. In the conventional Copenhagen narrative, this probability is epistemic: the wavefunction encodes incomplete knowledge about the outcome of a measurement, and “collapse” is a stochastic update of that knowledge. Alternative interpretations promote the wavefunction to an ontic field but typically retain a Minkowski picture in which time is a fundamental dimension and non-local correlations appear as “spooky” superluminal influences.

The TCGS framework rejects both the probabilistic and the Minkowskian premises. Following Ref. [1], we postulate a single static source manifold $(\mathcal{C}, G_{AB}, \Psi)$ that contains the full content of the universe, together with an embedded 3-D shadow manifold Σ and an immersion map

$$X : \Sigma \longrightarrow \mathcal{C}, \quad (g, \psi) = X^*(G, \Psi), \quad (1)$$

such that all observables on Σ are pullbacks of bulk fields. Apparent time evolution is not ontic but a foliation artifact: it arises from comparing different admissible slices of Σ through the same 4-D content. In this ontology, probability cannot be fundamental; instead, any probabilistic description must be a projection artifact of incomplete access to the bulk.

In this framework, electrons are described as “filaments”—1-D geometric traces through the 4-D bulk whose 3-D shadows on Σ reproduce the familiar orbital shapes. This framework exploits the analogy between filaments in a gravito-capillary foam and macroscopic magnetic surfaces, inspired by experiments on “magnetic orbitals” that visualize field geometries at the centimeter scale.[9] However, two shortcomings remained:

1. The wavefunction was treated ambiguously as both an epistemic probability cloud and an emergent property of the filament, without a clear resolution of the ψ -ontic / ψ -epistemic debate.
2. The nucleus was treated as a generic point-like anchor p_0 , and neutrinos were described as passive “guides” propagating changes in a stiffness field, rather than as active agents that modify the topology of the nuclear knot.

Recent empirical results now force a sharper geometric stance.

First, Yang *et al.* have implemented an experimental test of the Pusey–Barrett–Rudolph theorem on a superconducting quantum processor and found no evidence for the “forbidden” outcomes expected under ψ -epistemic models.[6] Together with the original PBR argument,[5] this result effectively rules out a large class of models in which the wavefunction is mere knowledge about an underlying 3-D microstate. Any viable completion of quantum mechanics must therefore locate its hidden variables outside the 3-D configuration space.

Second, the SNO+ Collaboration has reported the first real-time observation of charged-current interactions of solar ^8B neutrinos on ^{13}C via the reaction



followed by the β^+ decay $^{13}\text{N} \rightarrow ^{13}\text{C} + e^+ + \nu_e$ with a half-life of about 9.96 minutes.[7] The interaction is strongly isotope-selective: the abundant spin-0 isotope ^{12}C does not participate in this channel under the same conditions. This immediately suggests that the nucleus cannot be treated as a generic point source; its internal geometry and spin structure determine whether a neutrino can dock and transmute it.

Third, the ALICE Collaboration has shown that light nuclei such as the deuteron in high-energy proton–proton collisions are not formed by simple thermal coalescence of nucleons in the fireball. Instead, most deuterons descend from short-lived $\Delta(1232)$ resonances that decay outside the highest-curvature zone, before the final bound state crystallizes.[8] This result explicitly ties nuclear stability to a notion of resonance ancestry and to the geometric environment in which coalescence occurs.

The aim of this paper is to integrate these three pieces of evidence into a single, coherent revision of the geometric atom within the TCGS-SEQUENTION framework. The core corrections can be summarized as follows:

- **Wavefunction.** The combination of the PBR theorem and its experimental test grants an ontological license to treat the quantum state as real, but not as a 3-D field. In TCGS, the wavefunction becomes a tomographic map of a rigid 4-D filament in $\mathcal{C}$, and the “hidden variables” are reinterpreted as 4-D coordinates rather than local 3-D microstates.
- **Nucleus.** The nucleus is promoted from a point anchor to a *geometric knot*. Isotopes correspond to topologically distinct configurations of that knot; spin and parity encode its docking admissibility with respect to torsion-carrying probes such as neutrinos.
- **Neutrino.** Neutrinos are upgraded from “ Φ -guides” to *topological torsion operators*. A charged-current interaction provides a quantized unit of torsion that performs surgery on the nuclear singular set, pushing it into a metastable corridor in $\mathcal{C}$ whose corridor depth is measured by the observed half-life.
- **Stability.** Nuclear and electronic stability are unified under a single cartographic principle: only those configurations that correspond to geometrically stable isopotential pinches in the gravito-capillary foam can project coherently and persistently into Σ . Resonances and metastable states correspond to strained segments of the foam that eventually relax along extrinsic constitutive laws.

The manuscript is organized as follows. Section 2 briefly recalls the relevant axioms of TCGS and the basic notion of a geometric filament. Section 3 introduces the cartographic reinterpretation of the wavefunction, culminating in an “Ontological License” section that unifies the PBR theorem and its experimental implementation in the TCGS language. Section 4 develops the concept of nuclear crystallography, integrating SNO+ and ALICE results to define nuclear knots, isotope selectivity, and corridor depth. Section 5 formalizes the neutrino as a topological torsion operator. Section 6 returns to electronic orbitals, showing how the same geometric principles yield the familiar s, p, d, f families as torsion modes of filaments anchored to nuclear knots, and how macroscopic magnetic orbitals provide experimental analogues. Section 7 outlines empirical predictions and possible tests. Section 8 summarizes the conceptual and empirical status of the geometric atom.

2. TCGS-SEQUENTION Overview and Geometric Filaments

2.1. Axioms and Ontology

The TCGS-SEQUENTION framework is built on four axioms that invert the usual cosmological ontology.[1–3] We summarize the pieces relevant for atomic physics.

Axiom A1 (Whole Content). There exists a smooth 4-D Counterspace $(\mathcal{C}, G_{AB}, \Psi)$ containing the full content of all apparent “time stages” simultaneously. The observable 3-D world is not a self-contained manifold but an embedded shadow.

Axiom A2 (Identity of Source). There is a distinguished point $p_0 \in \mathcal{C}$ and an automorphism group $\text{Aut}(\mathcal{C}, G, \Psi)$ such that the fundamental singular set

$$S = \text{Orb}_{\text{Aut}}(p_0) \quad (3)$$

generates all shadow singularities. Black holes, elementary particles, and nuclear knots are all projection modalities of this single orbit.

Axiom A3 (Shadow Realization and Gauge Time). The observable world is a 3-manifold Σ embedded in $\mathcal{C}$ by an immersion $X : \Sigma \rightarrow \mathcal{C}$, and all observables (g, ψ) are pullbacks of bulk fields. Time has no ontic status; it is a gauge parameter encoding the choice of foliation of Σ through $\mathcal{C}$.

Axiom A4 (Parsimony and Extrinsic Law). No “dark species” or intrinsic randomness are introduced. Apparent dark effects in gravity and apparent randomness in quantum and biological phenomena arise from projection geometry and are encoded in a single extrinsic constitutive law.

In the gravitational sector, this extrinsic law takes the form of a modified Poisson equation,[2]

$$\nabla \cdot [\mu(|\nabla\Phi|/a_*) \nabla\Phi] = 4\pi G\rho_b, \quad (4)$$

where Φ is the gravitational potential, ρ_b is the baryonic mass density, μ is a monotone response function, and a_* is a geometry-derived acceleration scale. Dark-matter-like phenomena emerge as projection artifacts of this modified response.

An analogous extrinsic law governs informational fluxes in SEQUENTIAL biology, with a different mobility function μ_{bio} and scale $a^\dagger$. [3] In the atomic context, we will treat the stiffness of the electron filament and the torsional response of nuclear knots as manifestations of the same underlying extrinsic logic applied to different curvature regimes.

2.2. Isopotential Pinches and Filaments

Within this geometry, what is conventionally called a “particle” on the shadow Σ corresponds to a localized isopotential pinch—a region where the fields (G_{AB}, Ψ) induce high curvature and strong gradients in the pullback fields (g, ψ) . When such a pinch is traced along a foliation parameter, it defines a 4-D curve (or higher-dimensional ridge) in $\mathcal{C}$, which we call a *filament*.

For an electron in a bound state, the filament originates at a nuclear knot (a localized portion of S) and extends along a path in $\mathcal{C}$ determined by the extremization of a suitable action functional. Its 3-D shadow on Σ yields the familiar orbital shapes— s , p , d , f , and their hybrids—as isodensity contours of the induced field. These contours encode the local extrinsic curvature and torsion of the embedding $X : \Sigma \rightarrow \mathcal{C}$ over the relevant region,[4] thereby realizing at the atomic scale the same geometric chirality mechanism analysed in the Λ_b^0 system. Crucially, in TCGS the filament is ontic and static in $\mathcal{C}$; only the slice we use to interrogate it (and the coordinate labels we attach) changes.

In macroscopic experiments on magnetic orbitals, carefully constructed magnet-sensor systems produce field structures whose isosurfaces mimic atomic orbitals at human scales.[9] From the TCGS viewpoint, such experiments provide evidence that the same topology can be realized at many scales, in line with the gravito-capillary foam analogy.

3. Wavefunctions as Tomograms of 4-D Filaments

3.1. The ψ -Ontic vs. ψ -Epistemic Conflict

The Pusey–Barrett–Rudolph theorem targets models in which the quantum state ψ is interpreted as information (epistemic) about an underlying ontic state λ . [5] Under a set of assumptions—most notably *preparation independence* (independently prepared systems have factorizable distributions over λ)—PBR show that the supports of the epistemic distributions associated to distinct pure states cannot overlap if the model is to reproduce quantum predictions. In other words, ψ must be in one-to-one correspondence with the ontic state; it cannot be mere knowledge.

The original PBR theorem was purely theoretical. Yang *et al.* have now performed an experimental implementation on a superconducting qubit processor.[6] By preparing pairs of qubits in states that would lead to forbidden outcomes under overlapping ψ -epistemic models, they show that the frequencies of observed events are consistent with the ψ -ontic predictions and incompatible with large overlaps. In practice, this excludes a wide class of 3-D-local hidden-variable theories that would interpret ψ as incomplete knowledge about local degrees of freedom.

This creates a tension for realist models: if the wavefunction is real and lives on configuration space, then collapse seems to require non-local dynamical updates, in tension with relativistic causality. On the other hand, if we attempt to salvage locality by appealing to hidden variables, PBR tells us that those variables cannot live in the same 3-D shadow space in which we visualize the experiment.

3.2. Hidden Variables as 4-D Coordinates

In the TCGS ontology, this dilemma is resolved by changing the space in which hidden variables live. The fundamental ontic state of an N -qubit system is not a point in a 2^N -dimensional Hilbert space nor a list of classical values in Σ , but a geometric configuration in $\mathcal{C}$ involving:

- the positions of isopotential pinches associated with each qubit (filaments anchored to S);
- the extrinsic curvature and torsion of the embedding $X : \Sigma \rightarrow \mathcal{C}$ over the relevant region;

- the values of the global content fields Ψ in a neighborhood of the filaments.

The hidden variables are thus 4-D geometric data—coordinates and curvature invariants in $\mathcal{C}$ —and they are *necessarily* globally correlated because they all descend from the single orbit $S = \text{Orb}(p_0)$.

Preparation independence, as used in PBR, cannot hold in this ontology: any two qubits realized on the same chip are anchored to the same singular set and therefore share a non-trivial geometric ancestry. What appears as “conspiracy” from a 3-D perspective is simply static connectivity in the bulk. The PBR experiment does not rule out hidden variables; it rules out local hidden variables in Σ .

3.3. Degradation, Decoherence, and Extrinsic Curvature

Yang *et al.* report that the quality of the PBR violation degrades as the spatial separation between qubits increases and as the circuit depth grows, which they attribute to decoherence and control errors.[6] In TCGS, this pattern is reinterpreted as a cartographic measurement of extrinsic curvature.

Let $X : \Sigma \rightarrow \mathcal{C}$ be the embedding and consider a region containing two qubit filaments $F_1, F_2 \subset \mathcal{C}$. As we increase their spatial separation in Σ , the embedding must contort to accommodate both filaments simultaneously. The extrinsic constitutive law—the analogue of Eq. (4) for the stiffness of the embedding—imposes a cost on such contortions. The resulting projection biases manifest as “noise” or apparent decoherence in the experiments. The deeper the circuit (the more intricate the topological operation on the filaments), the more challenging it is for a single 3-D slice to represent the full 4-D structure without distortion.

This suggests a new interpretation of decoherence: not as a dynamical loss of quantum purity in time, but as a geometrical strain in representing a complex 4-D configuration within a limited 3-D cross-section. The experiments of Yang *et al.* can thus be read as a stress test of the map $X : \Sigma \rightarrow \mathcal{C}$.

3.4. Section 2.5: The Ontological License from PBR

We can now formulate the “Ontological License” provided by PBR and its experimental realization.

Proposition (Cartographic PBR). *Given Axioms A1–A3, the empirical confirmation of PBR-type inequalities implies: (1) the quantum state ψ cannot be purely epistemic on Σ ; and (2) any completion of quantum mechanics must place its hidden variables in $\mathcal{C}$ rather than in Σ .*

Sketch of argument. Assume for contradiction that there exists a ψ -epistemic model in which ψ is knowledge about 3-D local variables $\lambda \in \Lambda_\Sigma$. Preparation independence and the PBR construction then imply that certain outcome combinations should be strictly forbidden. Yang *et al.* observe no such forbidden outcomes within experimental precision.[5,6] The model is ruled out.

Within TCGS, the ontic state is a point in a space of 4-D geometries $(\mathcal{C}, G_{AB}, \Psi; S)$; its restriction to Σ yields incomplete information. Any attempt to confine λ to Σ alone misidentifies the level of description. The PBR result therefore shows that ignorance about a 3-D microstate is insufficient; the missing variables must be purely geometric in a higher-dimensional sense.

From this vantage point, the Yang experiment is not primarily a test of the reality of ψ *per se*, but a demonstration that distinct shadows cannot be generated from the same bulk configuration. Distinct wavefunctions correspond to distinct 4-D filaments, and the experimental frequencies verify the rigidity of these filaments against being simulated by overlapping 3-D distributions.

The conceptual payoff is that we are now licensed to interpret the atomic wavefunction as the *tomographic projection* of a 4-D object:

$$\psi(x) \sim \mathcal{T}[F \subset \mathcal{C}, X, \text{slice}], \quad (5)$$

where F is the electron filament, X the embedding, and “slice” denotes the chosen foliation. Probability densities $|\psi|^2$ quantify how often a given shadow region is intersected by admissible slices, not an intrinsic fuzziness of the electron.

4. Nuclear Crystallography: Knots, Isotopes, and Corridor Depth

4.1. From Point Masses to Geometric Knots

In conventional orbital models, the nucleus is often treated as a generic anchor at the location of the singularity p_0 in $\mathcal{C}$: a point-like mass that sources the Coulomb potential and pins the electron filament. The SNO+ evidence forces us to refine this picture.

The charged-current reaction $^{13}\text{C} + \nu_e \rightarrow ^{13}\text{N} + e^-$ is strongly isotope-selective.[7] The experiment measures a handful of events—consistent with expectations from the standard solar model—and reconstructs the delayed coincidence between the emitted electron and the subsequent decay of ^{13}N back to ^{13}C with a half-life of 9.96 minutes. Crucially, this process involves the spin-1/2 isotope ^{13}C and does not occur for the much more abundant spin-0 ^{12}C under the same conditions.

If the nucleus were a featureless point mass, the neutrino would couple indiscriminately to any carbon nucleus. Instead, the data reveal that the nuclear internal structure—its spin, parity, and shell configuration—acts as a selective lock that either admits or rejects the neutrino's torsion.

In TCGS language, we promote the nucleus to a *geometric knot*: a localized segment of the singular set $S \subset \mathcal{C}$ with non-trivial topology. Different isotopes of a given element correspond to distinct knot types, characterized by:

- a winding number or set of linking numbers with respect to the surrounding foam;
- a pattern of internal twists that encode spin and parity;
- the local curvature and torsion of the embedding around the knot.

The electron filament attaches to this knot and wraps around it according to boundary conditions derived from the Coulomb potential and the extrinsic law. Changes in the nuclear knot—such as those induced by neutrino interactions or hadronic resonances—reconfigure the boundary conditions and may create or destroy admissible electronic filaments.

4.2. Isotope Selectivity as Docking Admissibility

We can formalize isotope selectivity as a docking problem. Let $K(Z, A)$ denote the nuclear knot corresponding to a nucleus with charge Z and mass number A , and let τ_ν be a quantized torsion charge carried by a neutrino. A charged-current interaction is admissible only if there exists a smooth surgery

$$K(Z, A) \xrightarrow{\tau_\nu} K(Z + 1, A) \quad (6)$$

that preserves global topological invariants of the foam and gives rise to a new stable corridor.

In ^{13}C , the spin-1/2 structure provides a “geometric keyhole” that can absorb τ_ν and reconfigure the knot into ^{13}N . By contrast, the spin-0 configuration of ^{12}C lacks the necessary chiral asymmetry; the torsion key does not fit, and the channel is suppressed. This explains why the SNO+ reaction proceeds on ^{13}C but not on ^{12}C despite their similar chemical behavior.

4.3. Corridor Depth and Half-Lives

The SNO+ detection strategy exploits the delay between the prompt electron and the delayed positron from ^{13}N decay.[7] In a conventional temporal ontology, this is simply a 10-minute half-life. In the TCGS ontology, where time is a gauge variable, we reinterpret the half-life as a measure of corridor depth.

When the neutrino interacts with ^{13}C , it pushes the nuclear knot into a metastable corridor in $\mathcal{C}$, corresponding to the ^{13}N configuration. This corridor is a strained section of the gravito-capillary foam: a region where the curvature and torsion are high but still compatible with a temporary projection into Σ . The system remains in this corridor until the extrinsic constitutive law drives it back towards a lower-energy knot, ejecting the torsion difference as a positron.

We can parametrize this by a foliation parameter s along the embedding:

$$K(Z, A) \longrightarrow K^*(Z + 1, A) \longrightarrow K(Z, A), \quad (7)$$

where K^* denotes the metastable knot (e.g. ^{13}N). The half-life $T_{1/2}$ is proportional to the effective arc length L of the corridor along s :

$$T_{1/2} \propto L(K^*) = \int_{\gamma_{K^*}} \sqrt{g_{ss}} \, ds, \quad (8)$$

for an appropriate metric component g_{ss} induced by the embedding. Different isotopes and resonances correspond to corridors of different lengths and curvature profiles, leading naturally to a spectrum of half-lives.

4.4. ALICE Deuterons and Shadow Singularities

The ALICE Collaboration has provided a complementary view of nuclear crystallography at high energies. In proton–proton collisions, they measure correlations between pions and deuterons and infer that a large fraction of deuterons originate from the decay of intermediate $\Delta(1232)$ resonances, rather than from direct nucleon coalescence in the fireball.[8] This solves a longstanding puzzle in nuclear physics about the microscopic mechanism of light-nuclei formation.

From the TCGS perspective, Δ resonances are *shadow singularities*: tighter knots in S that temporarily localize curvature and torsion before relaxing into looser, more stable knots such as the deuteron. The fireball produced in the collision is a region of extreme curvature where stable isopotential pinches cannot exist. Instead, nuclei form only after the system has traveled along a corridor into a region where the curvature is sufficiently low for a stable pinch to crystallize.

Combining SNO+ and ALICE, we obtain a unified picture:

- At low energies, neutrinos push nuclear knots (e.g. ^{13}C) into metastable corridors (^{13}N), whose depth determines the observed delay.
- At high energies, hadronic collisions generate short-lived resonant knots (Δ) that serve as ancestors of stable nuclei (deuterons), with formation occurring outside the highest-curvature zone.

In both cases, stability is not an intrinsic property of pointlike particles but a condition of the projection depth from p_0 through the foam. The nucleus is a crystallized shadow of a 4-D resonance ancestry.

5. Neutrinos as Topological Torsion Operators

5.1. Fundamental Correction: From Guides to Operators

In earlier heuristic terms, neutrinos were sometimes described as Φ -guides: quanta that propagate modifications in a stiffness field and indirectly drive wavefunction collapse at a distance. This language now proves inadequate.

The SNO+ data show that neutrinos are not mere spectators or guides; they *perform* a topological operation on the nuclear knot.[7] The reaction $^{13}\text{C} + \nu_e \rightarrow ^{13}\text{N} + e^-$ changes the nuclear charge ($Z = 6 \rightarrow 7$), spin, and internal structure, and simultaneously creates an electron filament from the vacuum. The neutrino is the *operator* that mediates this transformation.

We therefore redefine:

Definition (Topological torsion operator). A neutrino is a localized packet of torsion in $\mathcal{C}$ that, upon docking to a nuclear knot $K(Z, A)$, implements a surgery on the singular set S :

$$K(Z, A) \xrightarrow{\tau_\nu} K^*(Z + 1, A) + F_{e^-}, \quad (9)$$

where K^* is a metastable knot and F_{e^-} is a newly created electron filament. The torsion charge τ_ν is quantized and conserved along the process; the emitted electron and the regenerated neutrino in the subsequent β^+ decay carry away the torsion difference required to restore global invariants.

This redefinition has several payoffs:

1. It unifies leptonic and hadronic processes: in both SNO+ and ALICE, transient resonant knots are created and then relaxed.
2. It explains why neutrino interactions are so sensitive to nuclear structure: docking requires a precise match between τ_ν and the chiral geometry of the knot.
3. It relocates the apparent non-locality of weak interactions from Minkowski spacetime to the higher-dimensional connectivity of $\mathcal{C}$. The neutrino follows a corridor in Counterspace, not a trajectory in ordinary space–time.

5.2. Corridor Depth as a Slice-Invariant

Because time is gauge, we cannot regard the “10 minutes” of the SNO+ delay as a primitive duration. Instead, we treat it as a slice-invariant associated with the metastable corridor. Operationally, half-lives are extracted from counting statistics; in TCGS these statistics reflect how often a random foliation intersects the relaxation point of the corridor.

Formally, let γ_{K^*} be the segment of S corresponding to a metastable knot (e.g. ^{13}N) and let s be a foliation parameter on Σ . The probability that a random slice intersects γ_{K^*} before it intersects the relaxation point determines the observed exponential decay law. The parameter “ t ” in the exponential $\exp(-t/T_{1/2})$ is a label on slices; the physics resides in the geometric measure of γ_{K^*} .

5.3. Nuclear Stability and Projection Coherence

The SNO+ paper notes that only transitions to the ground state of ^{13}N contribute significantly to the delayed coincidence signal; excited states decay too rapidly via proton emission to generate a usable corridor.[7] In TCGS terms, only those metastable corridors whose depth exceeds a certain threshold can project coherently into Σ as distinguishable states. Shallow corridors collapse so quickly in s that no foliation can isolate them; they are effectively integrated out.

This gives a geometric criterion for nuclear stability:

Criterion (Projection coherence). *A nuclear configuration corresponds to an observable isotope if and only if its associated corridor in $\mathcal{C}$ has sufficient depth and curvature profile that a non-negligible measure of admissible foliations intersect it before relaxation.*

Stable isotopes correspond to deep corrals anchored to low-curvature regions; short-lived isotopes and resonances correspond to shallow or highly curved corridors. The deuteron, for example, is the endpoint of a corridor descending from Δ resonances in ALICE; its binding energy and stability reflect the geometry of that corridor.[8]

6. Electronic Filaments and Magnetic Orbitals

6.1. Filaments as Torsion Modes

With the nuclear knot and neutrino operator properly defined, we can return to electron orbitals. In TCGS, an electron in a bound state is a filament anchored to a nuclear knot, with a shape determined by:

- the Coulomb potential and any additional fields;
- the local extrinsic curvature of the embedding;
- boundary conditions at the nuclear knot and at infinity;
- topological constraints inherited from S .

The familiar quantum numbers (n, ℓ, m) classify torsion modes of this filament. The radial quantum number n encodes how many nodes the filament has along a radial direction in Σ ; the orbital angular momentum ℓ and its projection m describe how many times the filament winds around the knot and with what azimuthal symmetry. The spin degree of freedom reflects a binary twist in the filament’s local framing, which realizes at the atomic scale the same geometric chirality mechanism previously analysed in the context of CP asymmetries in the Λ_b^0 system.[4]

Because the filament is static in $\mathcal{C}$, there is no “motion” of the electron in the usual sense. What we call dynamics—transitions between energy levels, emission or absorption of photons—corresponds to changes in the foliation and in the configuration of the surrounding foam. A photon is a reconfiguration of the field Ψ that reassigns curvature between different filaments.

6.2. Wavefunction as 3-D Tomogram

Given a filament $F \subset \mathcal{C}$, a specific foliation and embedding yield a shadow density on Σ :

$$\rho(x) \equiv |\psi(x)|^2 = \int_{F \cap X^{-1}(x)} w(s) ds, \quad (10)$$

where $w(s)$ encodes how the filament threads the slice at parameter s . In practice, the Schrödinger equation provides an efficient way of computing ρ without constructing F explicitly, but the geometric interpretation is that ψ is a tomogram of F . The PBR and Yang results guarantee that distinct filaments cannot yield the same tomogram without violating observed constraints.[5,6]

This resolves the apparent duality of the wavefunction: it is neither mere knowledge nor a mystical field in 3-D space, but a systematic summary of how a static 4-D filament intersects admissible slices.

6.3. Macroscopic Analogues: Magnetic Orbitals

Salcuni’s work on magnetic orbitals constructs macroscopic devices in which magnet configurations and Hall sensors produce field patterns that closely resemble atomic orbital shapes.[9] The experiments map equipotential surfaces and field line structures around magnet pairs, rings, and more complex arrangements, and show that by tuning geometry one can reproduce s -like, p -like, and higher-order patterns.

In the present framework, these experiments are interpreted as low-curvature realizations of the same topological constraints that shape electronic filaments. The magnets provide macroscopic sources that mimic the role of nuclear knots; the Hall sensors sample slices of the field in ways analogous to measurement apparatus in atomic physics. The fact that the same geometric families appear across many orders of magnitude in scale supports the view that orbitals are geometric rather than intrinsically probabilistic objects.

Moreover, the devices allow for direct visualization of how small changes in boundary conditions (e.g. magnet displacement) produce global reconfigurations of the field, analogous to how small perturbations in $\mathcal{C}$ can reshuffle electronic filaments and energy levels. They provide an accessible arena for testing ideas about filament rigidity and projection artifacts.

7. Predictions and Empirical Programme

The geometric atom outlined above is empirically equivalent to standard quantum mechanics at the level of single-atom spectra but differs in its deeper interpretation and in multi-scale predictions. Here we sketch several avenues for empirical discrimination or refinement.

7.1. Extended PBR-Type Experiments

If decoherence in PBR-type experiments is a measure of extrinsic curvature, as argued in Section 3, then carefully engineered variations in chip geometry and qubit placement should produce systematic, geometry-dependent deviations from simple noise models.[6] In particular:

- Placing qubits along a line versus on a curve should affect how the embedding strains to accommodate their filaments, modifying the pattern of PBR violations.
- Implementing PBR tests in three-dimensional qubit arrangements (e.g. multi-layer architectures) should probe regions of higher embedding curvature and reveal non-trivial anisotropies in the decoherence pattern.

A TCGS-inspired analysis would treat these effects as tomography of the embedding rather than as hardware imperfections to be minimized.

7.2. Neutrino Interactions on Other Isotopes

The interpretation of SNO+ as evidence for nuclear crystallography leads to several concrete predictions:

- Isotopes with similar shell structures and spin (e.g. other odd- A nuclei with $J = 1/2$) should exhibit analogous neutrino-induced corridors, with half-lives that scale with geometric properties of the knot rather than with naive shell-model expectations.
- Isotopes with closed shells and $J = 0$ should be comparatively inert under similar neutrino fluxes, reflecting the absence of an appropriate chiral keyhole.

Future liquid-scintillator experiments or neutrino observatories may be able to probe such channels, especially as detector masses and background control improve.

7.3. Resonance Ancestry and Corridor Families at the LHC

ALICE-like analyses can be extended to other light nuclei and hypernuclei, mapping the resonance ancestries and corridor depths associated with each stable species.[8] In TCGS, we expect that:

- Each stable nucleus corresponds to a family of resonance ancestors, forming a tree in $\mathcal{C}$ whose structure can be partially reconstructed from correlation data.
- The relative fractions of direct versus resonance-mediated formation encode information about curvature and torsion in the fireball region.

These patterns can be compared with TCGS-motivated models in which the foam is explicitly simulated and deuteron formation is treated as crystallization of isopotential pinches rather than probabilistic coalescence.

7.4. Macroscopic Corridor Analogues

In magnetic-orbital apparatus, it may be possible to create macroscopic analogs of metastable corridors by dynamically varying the magnet configuration while tracking field topology.[9] Transient field patterns that persist for a controlled range of parameter values before collapsing to a new configuration could serve as visualizations of corridor depth and relaxation in a low-energy limit.

Although the analogy is imperfect—the underlying physics is classical electromagnetism rather than nuclear or weak interactions—the topological features (knots, pinches, corridors) provide valuable intuition and an experimental sandbox adaptable to educational and outreach purposes.

8. Conclusions

We have constructed a revised and consolidated account of atomic structure within the Timeless Counterspace & Shadow Gravity (TCGS-SEQUENTION) framework, incorporating three key empirical developments: the PBR theorem and its experimental test on superconducting processors,[5,6] the SNO+ Collaboration's observation of charged-current solar-neutrino interactions on ^{13}C ,[7] and the ALICE Collaboration's reconstruction of deuteron formation from Δ resonances.[8]

The main conceptual moves are:

1. Reinterpreting the wavefunction as a 3-D tomogram of a rigid 4-D filament, with hidden variables residing in the bulk $\mathcal{C}$. PBR-type results exclude ψ -epistemic models on Σ but are naturally accommodated by geometric hidden variables.
2. Promoting the nucleus to a geometric knot whose topology, spin, and resonance ancestry determine isotope selectivity and stability. SNO+ and ALICE together define a cartography of nuclear corridors in Counterspace.

3. Upgrading neutrinos from passive guides to topological torsion operators that perform surgery on the singular set S . Half-lives and delays become measures of corridor depth along the foliation parameter.
4. Treating electronic orbitals as torsion modes of filaments anchored to nuclear knots, with macroscopic magnetic-orbital experiments serving as low-curvature analogues that illustrate the same geometric families.

The resulting “Crystallography of the Atom” is fully compatible with existing spectral and scattering data but offers a different explanatory hierarchy. Randomness and probability are demoted to projection artifacts; the underlying reality is a single, static, highly structured 4-D geometry in which all singularities descend from a unique origin p_0 . The atom, in this view, is not a pointlike nucleus surrounded by a probabilistic cloud, but a compact piece of a global gravito-capillary foam, with nuclear knots, electronic filaments, and neutrino corridors as different expressions of the same geometric language.

Further work will extend this programme to multi-electron atoms, chemical bonding, and condensed-matter phenomena, exploring how band structures and collective excitations emerge from networks of filaments and knots. On the experimental side, more refined PBR tests, neutrino-isotope studies, and heavy-ion tomography will continue to sharpen the empirical content of this geometric atom.

In this sense, atoms are *metacrystals*: localized crystallizations of a global four-dimensional geometry, rather than fundamental pointlike constituents of matter.

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