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# A Structural Prior for Dynamic Chirality-Induced Spin Selectivity

*The Parity Bridge Theorem (PR Book VI, 2026-04-13) meets Paltiel et al. (Sci. Adv., 2026-04-22)*

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## ABSTRACT

Paltiel, Goldberg, Yuran, Yochelis, Soh, Seibel, Gauss, Zilberg, Ozturk, Fransson, Krylov, and Naaman [26] have reported that the chirality-induced spin-selectivity (CISS) effect in chiral molecules is driven by a time-even pseudoscalar  $\mathbf{S} \cdot \boldsymbol{\mu}$  matrix element in the vibronic spin-orbit coupling, with the total angular momentum  $\mathbf{J}$  aligned along an “easy axis” whose direction differs between enantiomers at equal magnitude. The kinetic (non-thermodynamic) character of that mechanism resolves the long-standing puzzle that the weak-sector parity-violating energy bias  $\Delta E_{LR}/k_B T \sim 10^{-13}$  is by itself too small to drive universal homochirality by thermodynamic selection.

The present note records the fact that the structural requirement Paltiel et al. fill was, nine days prior, on the public archival record via the Panta Rhei 2nd Edition Book VI deposit (Zenodo DOI 10.5281/zenodo.19553667, record-creation timestamp 2026-04-13T11:32:53Z; Deutsche Nationalbibliothek record 1396000224, URN-minted 2026-04-13T11:46:30Z). Book VI’s *Parity Bridge Theorem* (VI.T01) proves that among the four primitive holonomy sectors of the Panta Rhei framework, only the weak sector admits a nontrivial polarity functional into the split-complex two-point object  $2_\tau$ . Book VI’s chapter on homochirality explicitly flags the  $10^{-13}$  thermal-noise gap (Ch. 16, §16.1.b), states that a non-thermal amplification channel is therefore *required*, and labels the four-force identification of that channel as *conjectural* (Table tab:ch16-four-forces; Remark VI.R09). We formalise the resulting structural-slot claim as a new  $\tau$ -effective lemma (VI.L18 *Kinetic Pseudoscalar Channel*), Lean-certified in the module `TauLib.BookVI.LifeCore.ParityBridge`, stating that any chirality-sign preserving channel between the weak-sector seed and biological homochirality must be realised by a parity-odd, time-even operator on the tensor product of the weak and electromagnetic holonomy sectors, operating above thermal scales.

Paltiel et al.’s vibronic  $\mathbf{S} \cdot \boldsymbol{\mu}$  mechanism satisfies the symmetry requirements of that slot by direct inspection of its parity and time-reversal transformations. The claim of this note is the *identification of the filler with the slot*, calibrated to structural-slot priority only: we do not claim to have predicted the specific vibronic-SOC decomposition, the atomic-plus-chiral SOC split, the  $\mathbf{J}$ -vector angular structure, or the 12%/28%/34% transport-asymmetry measurements. Those are Paltiel et al.’s original and independent contribution. We outline three falsification paths that would refute the slot-filler identification, and discuss what the identification means—and does not mean—for the programme’s Book VI scope-discipline ledger (VI.OP9, VI.R26).

**Keywords** Parity violation · homochirality · chirality-induced spin selectivity · CISS · vibronic spin-orbit coupling · pseudoscalar · category theory · Panta Rhei · pre-registration · priority of claim

## SCOPE DISCIPLINE

**Claim** Paltiel et al.’s vibronic CISS mechanism is a candidate filler for a non-thermal parity-odd amplification slot already exposed in Book VI.

**Non-claim** The note does not claim priority for the specific vibronic mechanism, transport measurements, or molecular decomposition reported by the anchor paper.

**External anchor** Paltiel et al. (2026) on dynamic chirality-induced spin selectivity.

**Framework bridge** Book VI Parity Bridge and homochirality scope ledger, especially the non-thermal amplification requirement.

**Verification / test** Refute the slot-filler identification by breaking the parity/time-reversal match, thermal-scale separation, or homochirality bridge.

**Status** Published response note.

## 1. INTRODUCTION

The puzzle of biological homochirality has been recognised since Pasteur's 1848 separation of tartrate crystals [3, 2]. Every protein in every living organism is built predominantly from L-amino acids; every strand of DNA or RNA is built on D-sugars; the preference is dominant, essentially universal, and has persisted for  $\sim 3.8$  billion years.<sup>1</sup> Classical chemistry provides no mechanism that selects one enantiomer over the other. Abiotic synthesis produces racemic mixtures [3]. Parity violation in the weak nuclear force [19, 34] is the only universal, structural source of handedness in fundamental physics, but the energy difference it induces between enantiomers,  $\Delta E_{LR} \sim 10^{-17} - 10^{-14}$  eV [28], is by itself utterly negligible on thermal scales:  $\Delta E_{LR}/k_B T$  at biological temperatures is of order  $10^{-13}$ . Some non-thermal amplification channel has been required by every serious proposal for the origin of homochirality [7, 32, 3], but the identity of that channel has remained controversial.

The chirality-induced spin-selectivity (CISS) effect [22, 4] has been the main experimental candidate for such a channel since the 2010s, with accumulating evidence that electron transport through chiral molecules produces spin polarisations too large to explain by equilibrium electrostatics and that those polarisations depend on molecular handedness. Several theoretical frameworks have been proposed: geometric spin-orbit coupling from the chiral molecular environment [31, 5], vibrational origins [8, 9, 21], spin-vibronic coupling with molecular magnetic substrates [23, 24, 25], and a recent "minimal model" reduction [29]. A key point of active disagreement has been whether the underlying CISS mechanism is thermodynamic or kinetic in character, and whether temperature sensitivity, spin-orbit coupling magnitude, or substrate-coupling are the controlling variables.

Paltiel, Goldberg, Yuran, Yochelis, Soh, Seibel, Gauss, Zilberg, Ozturk, Fransson, Krylov, and Naaman [26] (hereafter the Paltiel paper) consolidate this programme with a result of a different type. Using *ab initio* equation-of-motion coupled-cluster calculations on explicit chiral-molecule model systems and analytical decomposition of the spin-orbit coupling operator, they identify the dominant enantiomer-distinguishing operator as the time-even pseudoscalar

$$V_{\text{SOC}}^{\text{chiral}} \supset \mathbf{S} \cdot \mu(Q), \quad (1)$$

where  $\mathbf{S}$  is the spin operator and  $\mu(Q)$  is a dipole-moment operator whose value depends on nuclear vibrational coordinate  $Q$ ; the explicit time-dependence of  $\mu(Q)$  through nuclear vibrations is what distinguishes the mechanism from any equilibrium parity-bias picture. The key structural point is that, because  $\mathbf{S} \cdot \mu$  is a parity-odd time-even pseudoscalar, its matrix elements between spin-polarised electronic states differ in sign between the two enantiomers of a chiral molecule, even when the eigenvalues of the total Hamiltonian are identical (which they are, because

<sup>1</sup>Strict universality admits well-known exceptions: D-alanine and D-glutamate occur in bacterial peptidoglycan, D-amino acids appear in non-ribosomal peptides such as gramicidin, D-serine and D-aspartate are CNS signalling molecules in mammals, and racemisation of L-aspartate accumulates measurably in aged eye lens and tooth dentin. Meteoritic samples such as the Murchison and Tagish Lake chondrites contain amino acids with small but significant L-excesses in several non-proteinogenic species [6, 27, 14], a fact that is *consistent with*—rather than counter to—the universality claim. These exceptions and the meteoritic data do not undermine the slot claim: the argument of the present note requires a dominant sign, not strict exactness.

parity and time-reversal are each individually preserved by the electroweak-neutral electronic Hamiltonian). *Kinematically* distinct outcomes emerge between enantiomers even though *energetically* they are degenerate. This is the non-thermodynamic amplification channel the field has been looking for.

The present note is a response paper. Its claim is not that Paltiel et al.'s mechanism is correct—we take no independent position on that—but that the *structural slot* their mechanism fills was on the public record nine days before their publication (though their work was submitted to *Science Advances* on 2025-10-08 and accepted on 2026-03-25, and is thus developed entirely independently of the Panta Rhei deposit), in the Panta Rhei 2nd Edition Book VI (Categorical Life) deposit. Book VI's Parity Bridge Theorem (VI.T01) states that among the four primitive holonomy sectors of the Panta Rhei framework, only the weak sector admits a nontrivial polarity functional into the split-complex two-point object  $2_r$ , and that the transition from the physics layer  $E_1$  to the life layer  $E_2$  must factor through it. Book VI's Chapter 16 on homochirality explicitly acknowledges that the thermal-scale energy bias is too small to drive selection by itself (ch. 16, §16.1, item (b)) [12]; requires a non-thermal amplification channel (ch. 16, §16.2); and labels the four-force mechanistic identification of that channel as *conjectural* (ch. 16, Table tab:ch16-four-forces and Remark VI.R09, rem:vi-conjectural-scope).

In this note we:

1. state and formalise the structural-slot claim as a new  $\tau$ -effective lemma (VI.L18 *Kinetic Pseudoscalar Channel*), Lean-certified in `TauLib.BookVI.LifeCore.ParityBridge`;
2. identify Paltiel et al.'s vibronic  $\mathbf{S} \cdot \mu$  operator as an exact filler of that slot;
3. state the priority of claim with scope discipline: Panta Rhei's public record establishes slot priority, not mechanism priority;
4. list three falsification paths for the slot-filler identification;
5. relate the result to adjacent proposals in the CISS literature [8, 21, 29, 5] and to Ozturk-Sasselov's prebiotic RAO/magnetite model for the specific terrestrial handedness [23, 24, 25].

The note is written to be read on its own; Section 3 summarises the parts of Book VI needed to follow the slot claim, and Section 4 summarises the parts of the Paltiel paper needed to follow the filler claim.

## 2. PRIORITY OF CLAIM

The structural content of this note was placed on the public record before the experimental-theoretical mechanism it identifies with. The claim is therefore a *calibrated priority of slot*, not a claim to have predicted the specific mechanism.

**The deposit..** Panta Rhei, 2nd Edition, Book VI, *Categorical Life* [12, 10] (Fuchs & Fuchs, 2026), was deposited on two independent public archives:

- **Zenodo:** DOI [10.5281/zenodo.19553667](https://doi.org/10.5281/zenodo.19553667), record-creation timestamp **2026-04-13T11:32:53Z**.
- **Deutsche Nationalbibliothek:** record 1396000224, URN [urn:nbn:de:101:1-2604131146307.688797894217](https://nbn-resolving.org/urn:nbn:de:101:1-2604131146307.688797894217), URN-minted **2026-04-13T11:46:30Z** (13 minutes after the Zenodo record-creation event), catalogue entry modified 2026-04-14T03:33:59Z.

Both archival events precede the Paltiel et al. *Science Advances* publication of 2026-04-22 by nine days.<sup>2</sup> Chapter 3 (Parity Bridge) and Chapter 16 (Homochirality: The Parity Bridge Made Visible) of that deposit contain, verbatim:

- (i) The *Parity Bridge Theorem* (VI.T01): among the four primitive holonomy sectors at  $E_1$ , only the weak sector admits a nontrivial polarity functional into  $2_\tau$ ; the  $E_1 \rightarrow E_2$  transition factors through it uniquely.
- (ii) An on-record acknowledgement that the weak-sector energy bias  $\Delta E_{LR}/k_B T \sim 10^{-13}$  is too small by many orders of magnitude to drive homochirality by thermodynamic selection alone (Ch. 16, §16.1, item (b)).
- (iii) A structural requirement for an amplification channel between the weak-sector seed and the biological outcome, together with an explicit flag that the mechanism occupying that slot was *conjectural* at deposit time: Yang–Mills seed marked  $\tau$ -effective, Riemann/Hodge/Poincaré entries marked conjectural (Ch. 16, Table tab: ch16-four-forces; Remark VI.R09 rem: vi-conjectural-scope).

**The  $\tau$ -effective lemma..** The structural content above has been mechanised as VI.L18 (*Kinetic Pseudoscalar Channel*) in the TAU LIB formal library, module TauLib.BookVI.LifeCore.ParityBridge, theorem Tau.BookVI.ParityBridge.kinetic\_pseudoscalar\_channel. The lemma states: *any amplification channel between the weak-sector chirality seed (VI.D72) and biological homochirality, preserving chirality sign through the propagation functor (VI.D71, VI.T41), must be realized by a parity-odd, time-even operator on the tensor product of the weak and electromagnetic holonomy sectors, operating above thermal scales.* Scope:  $\tau$ -effective. Proof: by the rfl invariants of the KineticPseudoscalarChannel structure together with the already-certified VI.L01 (weak-sector uniqueness) and VI.T01 (Parity Bridge).

**The match..** Paltiel, Goldberg, Yuran, Yochelis, Soh, Seibel, Gauss, Zilberg, Ozturk, Fransson, Krylov, and Naaman, *Dynamic breaking of mirror symmetry in spin-dependent electron transport through chiral media causes enantiomeric excesses*, *Science Advances* **12**, eaec9325 (2026), DOI 10.1126/sciadv.aec9325, submitted 2025-10-08, accepted 2026-03-25, **published 2026-04-22**, derives, from first principles, a time-even pseudoscalar  $\mathbf{S} \cdot \mu$  matrix element in the vibronic spin–orbit coupling that asymmetrises electron transport through chiral media at room temperature. The mechanism is kinetic rather than thermodynamic; it operates well above thermal scales.

**The priority statement, calibrated..** The two records are independent: Paltiel et al. were submitted in October 2025, six months before the PR April deposit, and the Panta Rhei programme has been developing Book VI’s Parity Bridge material over multiple years. Neither team influenced the other. What the deposit priority establishes is a *structural slot claim* — that Panta Rhei Book VI had on public record, by 2026-04-

<sup>2</sup>Preprint-priority verification: we searched arXiv on 2026-04-24 for “Paltiel Naaman dynamic mirror symmetry” and obtained no matching preprint. Programmatic searches of bioRxiv and ChemRxiv on the same date returned access errors (HTTP 403); we recommend that the reader verify these manually prior to citing the priority claim. Earlier Paltiel/Naaman works on the CISS effect [22, 1, 4] are public record and are acknowledged here; the specific derivation of the vibronic  $\mathbf{S} \cdot \mu$  pseudoscalar operator in the 2026-04-22 *Science Advances* paper is the object of the priority comparison.

13T11:32:53Z, the requirement that a non-thermal amplification channel must exist between the weak-sector chirality seed and biological homochirality, together with the identification of spin-dependent dynamics on chiral molecular environments as the slot to be filled (VI.L18 in TAU LIB). Paltiel et al., published nine days later, provide the specific mechanism that fills that slot. The claim of the present note is the *identification of the filler with the slot*, not a claim to have predicted the specific vibronic SOC decomposition.

**What is explicitly not claimed..** Panta Rhei did not predict: the specific form of the  $\mathbf{S} \cdot \mu$  pseudoscalar operator; the atomic-plus-chiral vibronic SOC split; the  $\mathbf{J}$ -vector equal-magnitude-but-different-direction structure between enantiomers; or the 12%/28%/34% transport-asymmetry measurements reported in Paltiel et al. Those are Paltiel et al.’s original and independent contribution, and their priority is uncontested.

### 3. THE PARITY BRIDGE AND THE AMPLIFICATION SLOT

This section reviews the Book VI structural argument in the form needed for the slot claim. Nothing here is new; all statements are from the 2026-04-13 Zenodo deposit [12], chapters 3 and 16.

#### 3.1 Polarity functional and holonomy sectors

In the Panta Rhei framework, the boundary holonomy algebra  $H_\partial$  at the physics enrichment layer  $E_1$  decomposes into four primitive sectors, corresponding to the four fundamental forces of the Standard Model plus general relativity. Following the canonical mapping established in Book III, Chapter 10 and Book IV, Chapters 1 and 9 [11], the generator-to-sector assignment is  $\mathcal{S}_{\text{weak}}$  (weak interaction, generator  $\pi$ , A-sector),  $\mathcal{S}_{\text{EM}}$  (electromagnetism, generator  $\gamma$ , B-sector),  $\mathcal{S}_{\text{strong}}$  (QCD colour, generator  $\eta$ , C-sector), and  $\mathcal{S}_{\text{GR}}$  (gravitation, generator  $\alpha$ , D-sector).<sup>3</sup> The fifth generator  $\omega$  (Higgs) does not appear among the four primitive sectors tested in Book VI Chapter 3 and is outside the scope of the polarity functional defined there.

**Definition 3.1** (Polarity functional, VI.D01). *Let  $\mathcal{S}$  be a primitive holonomy sector of  $H_\partial$  at  $E_1$ . The polarity functional of  $\mathcal{S}$  is the map*

$$P_{\mathcal{S}}: \text{End}(\mathcal{S}) \longrightarrow 2_\tau, \quad (2)$$

where  $2_\tau = \{+, -\}$  is the split-complex idempotent two-point object, defined by  $P_{\mathcal{S}}(f) = +$  if  $f$  preserves the orientation of the holonomy cycle in  $\mathcal{S}$  and  $P_{\mathcal{S}}(f) = -$  if  $f$  reverses it.  $P_{\mathcal{S}}$  is trivial if it is constant equal to  $+$ , and nontrivial otherwise.

**Lemma 3.2** (Weak-sector uniqueness, VI.L01). *Among the four primitive holonomy sectors,*

$$P_{\mathcal{S}} \text{ is nontrivial} \iff \mathcal{S} = \mathcal{S}_{\text{weak}}. \quad (3)$$

*The electromagnetic, strong, and gravitational Lagrangians are parity-invariant. The electroweak sector is maximally parity-violating: the  $V$ – $A$  coupling to left-handed fermions is exact at tree*

<sup>3</sup>The Book VI Chapter 3 exposition of the Parity Bridge Theorem uses a local notational convention in which  $\pi$  labels the strong sector and  $\eta$  labels the weak sector. For this note we follow the canonical Book III/Book IV mapping throughout. The physical content of VI.T01 is unchanged: the weak-interaction sector, regardless of generator symbol, is the unique parity-violating primitive sector.

level [19, 34], and the  $\sigma = C_\tau$  Majorana identity at the neutrino level (PR Book IV Theorem IV.T146) motivates the structural argument within the framework itself.<sup>4</sup>

**Theorem 3.3 (Parity Bridge, VI.T01).** *The transition from the physics layer  $E_1$  to the life layer  $E_2$  factors uniquely through the weak sector:*

$$E_1 \xrightarrow{P_{\text{weak}}} 2_\tau \xrightarrow{\text{SelfDesc}} E_2. \quad (4)$$

*No other sector provides a polarity seed: by Lemma 3.2 no other sector even admits a nontrivial  $P_S$ . The bridge is narrow and canonical.*

Theorem 3.3 is the central result of Book VI Part I. It does not by itself explain how the weak-sector polarity seed reaches the biological carriers that make up all known life; that is the work of Chapter 16 and of the present note. But it does fix the direction of the argument: whatever amplification channel carries the chirality sign from  $E_1$  to  $E_2$ , it must factor through the weak sector, and the polarity seed it delivers to the carriers lives in the split-complex two-point object  $2_\tau$ .

### 3.2 The thermal-noise gap

Chapter 16 of Book VI states the puzzle in four facts (§16.1, items (a)–(d)) [12]. The essential quantitative one for the present note is item (b):

*The weak-force energy bias is negligible on thermal scales. Parity violation in the weak nuclear force creates an energy difference  $\Delta E_{LR} \sim 10^{-17} - 10^{-14}$  eV between enantiomers. Thermal energy at biological temperatures is  $k_B T \sim 0.025$  eV—a factor of  $10^{11} - 10^{13}$  larger.*

The immediate consequence is that a purely thermodynamic picture of chirality selection—enantiomers in Boltzmann-weighted equilibrium with  $\Delta E_{LR}$  as the selective pressure—cannot work. An enantiomeric excess of order  $\exp(-\Delta E_{LR}/k_B T) - 1 \sim 10^{-13}$  is not amplifiable to universality by any stationary autocatalytic mechanism under realistic abiotic conditions. A non-thermal—that is, kinetic—amplification channel is therefore structurally required for any route from the weak-sector seed to universal biological homochirality.

### 3.3 The structural-slot requirement

Chapter 16 of Book VI identifies four kinematic roles that the amplification pipeline must play: seed, amplification, stabilisation, and lock-in [12]. Only the first—the seed—is directly sourced by the weak sector. The other three are identified with the Riemann, Hodge, and Poincaré forces of the programme, but that identification is itself flagged as *conjectural* in the book’s scope ledger:

*The four-force picture acquires additional weight from the comparison with the three parity-symmetric forces ... only the seed (Yang–Mills) carries  $\tau$ -effective*

<sup>4</sup>The Lean certificate for VI.L01 in `TauLib.BookVI.LifeCore.ParityBridge` is by `rfl` on the count of nontrivial sectors among the four primitive ones; IV.T146 enters as the physical justification for placing that one nontrivial polarity on the weak sector, not as a logical premise of the Lean proof. See Appendix A.

*scope; the amplification, stabilisation, and lock-in mechanisms are conjectural identifications of formal structures with specific physical processes.* (Ch. 16, Table `tab:ch16-four-forces`)

and again, in the Not claimed (conjectural) list of Remark VI.R09:

*That the four-force convergence mechanism is the correct mechanistic account of amplification. The structural derivation via `SelfDesc` closure is  $\tau$ -effective; the specific identification of amplification with the Riemann force remains conjectural.* (Remark VI.R09, `rem:vi-conjectural-scope`)

Reading these two passages together: Book VI’s on-record position at the time of the Zenodo deposit (2026-04-13) was that a non-thermal amplification channel is *required* (§3.2), and that its specific mechanism is *open* (the present subsection). The slot is well-defined structurally; the filler is not specified by the framework.

### 3.4 Formalisation as a $\tau$ -effective lemma

The present note formalises the slot requirement as a standalone  $\tau$ -effective lemma within Book VI, Lean-certified in `TauLib.BookVI.LifeCore.ParityBridge` [13]:

**Lemma 3.4 (Kinetic Pseudoscalar Channel, VI.L18).** *Any amplification channel between the weak-sector chirality seed (VI.D72) and biological homochirality, preserving chirality sign through the polarity propagation functor (VI.D71, VI.T41), must be realised by a parity-odd, time-even operator on the tensor product  $\mathcal{S}_{\text{weak}} \otimes \mathcal{S}_{\text{EM}}$  of the weak and electromagnetic holonomy sectors, with the operator’s matrix elements bounded away from zero above  $k_B T \approx 0.025$  eV. Scope:  $\tau$ -effective.*

*Proof sketch.* The operator must be parity-odd: otherwise its matrix elements are equal in the two enantiomers and no chirality sign is transported. It must be time-even: a time-odd operator vanishes identically in time-reversal symmetric steady states, which describe the ensemble-averaged abiotic chemistry that preceded life. It must be realised on  $\mathcal{S}_{\text{weak}} \otimes \mathcal{S}_{\text{EM}}$ : the weak sector supplies the parity-odd factor (by Lemma 3.2), and the electromagnetic sector supplies the carrier degree of freedom on which the chemistry happens (no other primitive sector couples to molecular electronic structure at the relevant scales). It must be non-thermal: by §3.2, any thermodynamic selection at biological temperatures is suppressed by  $10^{-13}$  and cannot drive universality on the observed timescale. The full Lean proof is by `rfl` on the invariants of the `KineticPseudoscalarChannel` structure together with `weak_sector_uniqueness` (VI.L01) and `parity_bridge_theorem` (VI.T01).  $\square$

Lemma 3.4 does not by itself specify the operator; it specifies the structural slot any valid operator must occupy. The content of Section 4 is that Paltiel et al.’s vibronic  $\mathbf{S} \cdot \mu$  occupies exactly this slot.

The symmetry ledger of VI.L18 is summarised in Table 1.

**Remark 3.5 (On the uniqueness of  $\mathbf{S} \cdot \mu$  at leading order).** Lemma 3.4 does not uniquely determine the operator at subleading orders. Higher-rank pseudoscalar contractions

Operator type	P	T	Admissible filler?
scalar	+	+	no (no chirality sign)
pseudoscalar	−	+	<b>yes (VI.L18 slot)</b>
vector	−	−	no (time-odd)
axial vector	+	−	no (both wrong)

**Table 1.** Parity–time-reversal ledger for the amplification-channel operator. The VI.L18 slot is occupied only by parity-odd, time-even operators. Among these, the lowest-dimension contraction on  $\mathcal{S}_{\text{weak}} \otimes \mathcal{S}_{\text{EM}}$  is  $\mathbf{S} \cdot \mu$ —the Paltiel operator.

exist, such as  $\mathbf{S} \cdot (\mathbf{r} \times \nabla)$  or  $\mathbf{S} \cdot (\mathbf{r} \times \mu)$ , and may contribute. What Lemma 3.4 does specify is the symmetry class of the leading operator: parity-odd, time-even, bilinear on  $\mathcal{S}_{\text{weak}} \otimes \mathcal{S}_{\text{EM}}$ . The Paltiel paper derives  $\mathbf{S} \cdot \mu$  as the dominant contribution *ab initio*; the slot claim is that no operator outside this symmetry class could have played that role regardless of the details.

## 4. THE PALTIEL MECHANISM

This section summarises the parts of the Paltiel paper [26] needed to make the slot–filler identification in Section 5. Paltiel et al.’s result is the original; nothing here is ours.

### 4.1 The operator decomposition

The spin–orbit coupling operator of a molecular Hamiltonian may be decomposed into a purely atomic contribution  $V_{\text{SOC}}^{\text{atomic}}$  (each atom’s single-centre spin–orbit term) and a chirality-induced remainder  $V_{\text{SOC}}^{\text{chiral}}$  that vanishes for an achiral molecule:

$$V_{\text{SOC}} = V_{\text{SOC}}^{\text{atomic}} + V_{\text{SOC}}^{\text{chiral}}. \quad (5)$$

The atomic part is unchanged under mirror reflection; it is the same in the two enantiomers of any chiral molecule and cannot by itself select a handedness. The chiral part vanishes identically when the instantaneous nuclear framework is  $S_n$ -symmetric (achiral) and is what distinguishes the enantiomers of a chiral molecule.

Paltiel et al. show that the leading contribution to  $V_{\text{SOC}}^{\text{chiral}}$  can be written as

$$V_{\text{SOC}}^{\text{chiral}} \supset \mathbf{S} \cdot \mu(Q), \quad (6)$$

where  $\mathbf{S}$  is the electron-spin operator,  $\mu(Q)$  is a dipole operator parametrised by the nuclear vibrational coordinate  $Q$ , and the product is a scalar in the rotational sense but a *pseudoscalar* under the combined action of spatial parity and rotational invariance.

### 4.2 Symmetry classification

Under spatial parity  $\mathbf{P} : \mathbf{r} \mapsto -\mathbf{r}$ , spin is axial (pseudovector-valued), the electronic dipole operator  $\mu$  at clamped nuclei is polar (vector-valued), and the nuclear vibrational coordinate  $Q$  transforms as  $Q \mapsto -Q$ :

$$\mathbf{S} \xrightarrow{\mathbf{P}} +\mathbf{S}, \quad \mu(Q) \xrightarrow{\mathbf{P}} -\mu(-Q), \quad (7)$$

so  $\mathbf{S} \cdot \mu(Q) \xrightarrow{\mathbf{P}} -\mathbf{S} \cdot \mu(-Q)$ : the operator is parity-odd at the level of the contracted vibronic object, and its matrix elements change sign between enantiomers at fixed nuclear geometry. Under time reversal  $\mathbf{T}$ ,

$$\mathbf{S} \xrightarrow{\mathbf{T}} -\mathbf{S}, \quad \mu(Q) \xrightarrow{\mathbf{T}} -\mu(Q), \quad (8)$$

so  $\mathbf{S} \cdot \mu(Q) \xrightarrow{\mathbf{T}} +\mathbf{S} \cdot \mu(Q)$ : the operator is time-even.

This places  $\mathbf{S} \cdot \mu$  in the parity-odd, time-even row of Table 1.

## 4.3 Dynamic mirror-symmetry breaking and kinetic asymmetry

The central argument of the Paltiel paper is that, although  $V_{\text{SOC}}^{\text{chiral}}$  does not change the *eigenvalues* of the total molecular Hamiltonian when parity and time-reversal are each individually preserved, it does change the *phases of the matrix elements* between spin states, and those phase changes propagate into distinct *kinetics* of electron transport through chiral media of opposite handedness. Paltiel et al. report that the total molecular angular momentum vector  $\mathbf{J}$  in each enantiomer is aligned along an “easy axis” of equal magnitude but differing orientation relative to the electric dipole vector  $\mu$ , quantified by the angle between  $\mathbf{J}$  and  $\mu$  (their Figure 2; we refer the reader to the original paper for the exact formulation). The quantitative result is an enantiomer-dependent spin-polarisation asymmetry of  $28 \pm 6\%$  in chiral gold,  $12 \pm 4\%$  in chiral silver, and  $34 \pm 10\%$  in polyaniline on gold, measured at room temperature.

Crucially, the mechanism is kinetic rather than thermodynamic: it operates through the coupling between nuclear-vibrational dynamics and the spin–orbit-induced phase differences, and it therefore does not rely on Boltzmann-weighted energy differences between enantiomers. This is the non-thermal character that distinguishes the mechanism from the  $\Delta E_{LR}$ -based pictures of earlier decades, and it is what makes the mechanism a viable amplification channel at biological temperatures.

## 5. IDENTIFICATION OF FILLER WITH SLOT

We can now state the identification.

**Proposition 5.1 (Slot–Filler Identification).** *Paltiel et al.’s vibronic  $\mathbf{S} \cdot \mu(Q)$  operator (6) is an admissible filler of the VI.L18 structural slot (Lemma 3.4). Specifically:*

- (i)  $\mathbf{S} \cdot \mu$  is parity-odd and time-even (§4.2);
- (ii)  $\mathbf{S} \cdot \mu$  can be identified with an operator on the tensor product  $\mathcal{S}_{\text{weak}} \otimes \mathcal{S}_{\text{EM}}$ : the spin  $\mathbf{S}$  transforms in the same irreducible representation as the weak-sector polarity generator, and the dipole  $\mu$  transforms in the same irreducible representation as the EM-sector dipole; the identification is at the level of symmetry class, not a physical derivation;
- (iii) the mechanism is kinetic and operates above thermal scales, with measured asymmetries of order  $10^{-1}$  [26]—eleven to twelve orders of magnitude larger than the thermodynamic expectation from  $\Delta E_{LR}/k_B T$  alone.

**Scope:** (i) [Established] (direct calculation of the parity and time-reversal transformations); (ii) [Metaphorical] (a symmetry-class analogy, not a conjecture to be derived from the framework);<sup>5</sup>

<sup>5</sup>We apply the programme’s four-label scope discipline strictly. *Metaphorical* (as opposed to *conjectural*) is the correct label for a structural analogy that is calibrated to symmetry alone: the claim “ $\mathbf{S}$  transforms in the same irreducible representation as the weak-sector polarity generator” is not the kind of statement that could be proven true or false inside the framework the way a conjectural claim could. Conjectural claims are provisionally believed true and expected to be derivable with further work; metaphorical claims are structural identifications of different objects that happen to share symmetry class. Drawing this distinction sharply here is doubly important in a paper whose core argument is slot–mechanism discipline.

(iii) [ $\tau$ -Effective] (the non-thermal condition is entailed by VI.L18 together with the empirical measurement).

*Proof.* (i) is Section 4.2. (ii) is a symmetry-class match:  $\mathbf{S}$  and  $\mu$  transform in the irreducible representations associated with the weak and electromagnetic sectors respectively, so their contraction can be identified with an operator on  $\mathcal{S}_{\text{weak}} \otimes \mathcal{S}_{\text{EM}}$  at the symmetry level. (iii) is the kinetic-vs-thermodynamic argument of Paltiel et al. [26] together with the  $\Delta E_{LR}/k_B T \sim 10^{-13}$  ratio of the thermal-noise gap (§3.2).  $\square$

The identification is symmetry-level. It does not imply that Panta Rhei's framework *derives* the vibronic  $\mathbf{S} \cdot \mu$  operator from first principles within the programme; it implies only that the operator occupies a slot the programme independently required to exist. The converse identification—that Paltiel et al.'s result constrains the slot in ways tighter than VI.L18 expresses—is an open research direction (Section 9).

## 6. FALSIFICATION PATHS

The slot–filler identification is falsifiable on at least three axes.

**F1. Parity–time symmetry violation of the CISS operator.** If independent work identifies an operator outside the parity-odd, time-even symmetry class as the dominant CISS channel—for example, if the controlling contribution turns out to be time-odd (a dissipative chirality-induced Berry-phase term [31]) or parity-even (a scalar coupling that fails to distinguish enantiomers by itself and relies on an external chiral field)—then the operator is not an admissible filler of the VI.L18 slot. The slot claim survives (VI.L18 is structural), but the identification with Paltiel et al.'s operator fails.

**F2. Thermal dominance.** If future measurements show that the CISS asymmetry is governed by a thermodynamic rather than kinetic mechanism, the slot characterisation in Lemma 3.4 is too narrow. The operational test is a direct temperature-dependence experiment: if the asymmetry scales as  $\exp(-\Delta E/k_B T)$  for some  $\Delta E$  comparable to thermal energies (a clear Arrhenius signature from, e.g., 77 K to 300 K on the same molecular system [21, 30]), the phenomenon is thermodynamic; if the asymmetry is temperature-independent or depends on temperature only through phonon occupation, the phenomenon is kinetic. In the thermodynamic case, VI.L18's non-thermal condition would need to be relaxed or replaced by a kinetic–thermodynamic hybrid, and the slot claim would have to be weakened. The evidence currently points the kinetic way [26, 21, 29]; but the falsification path is open.

**F3. Non-weak-sector chirality source.** If a non-weak-sector source of chirality at  $E_1$  is discovered—for instance, a parity-violating sector missed in the four-sector decomposition, or a parity-violating coupling of the Higgs sector incorrectly classified as trivial—then the uniqueness of  $P_{\text{weak}}$  in Lemma 3.2 fails, and the Parity Bridge Theorem (VI.T01) is *falsified*. VI.L18's symmetry characterisation of the slot, and the slot–filler identification with the Paltiel operator, would have to be rebuilt from a different structural foundation. We take this axis seriously: it is not a mere rescoping but a genuine falsifier of the theorem in its current form. No credible evidence for such a source is currently known; candidate evidence would be a direct measurement of a

chirality-selective coupling in a non-weak sector, or a theoretical derivation showing the Higgs sector admits nontrivial polarity.

## 7. RELATED WORK

The vibronic-origin programme in CISS has been developed by several groups. Fransson [8, 9] established that exchange splitting and chiral-induced spin selectivity are driven by spin–phonon coupling, not by equilibrium electronic structure alone; this is a direct precursor to the Paltiel decomposition. Hededård [16] developed a complementary spin-dynamics framework focused on the coherent vibronic wavepacket. Miwa et al. [21] showed experimentally that spin polarisation in chiral molecules is driven by molecular vibrations above thermal scales. Savi–Celada et al. [29] reduced the argument to a minimal model amenable to analytic treatment. Seibel et al. [30] observed the CISS effect on ultrafast timescales in photoswitching molecules. Each of these adjacent proposals is an admissible candidate for VI.L18's slot; the Paltiel paper is the one that, at the time of writing, presents the cleanest analytical derivation of the pseudoscalar operator from *ab initio* electronic-structure theory.

In parallel, Ozturk, Sasselov, and collaborators [24, 23, 25] have developed a prebiotic pathway in which the crystallisation of an RNA aminooxazoline (RAO) precursor on a ferromagnetic substrate (magnetite) transfers chiral information through spin-polarised electron transport. That mechanism is *also* a filler of the VI.L18 slot, and the Paltiel paper is compatible with the Ozturk–Sasselov picture as one plausible route for the terrestrial emergence of homochirality.<sup>7</sup> We do not take an independent position on which realisation (direct CISS, magnetite-mediated RAO crystallisation, or a hybrid) is the relevant one for the origin of terrestrial life; the slot claim is agnostic between fillers in the same symmetry class.

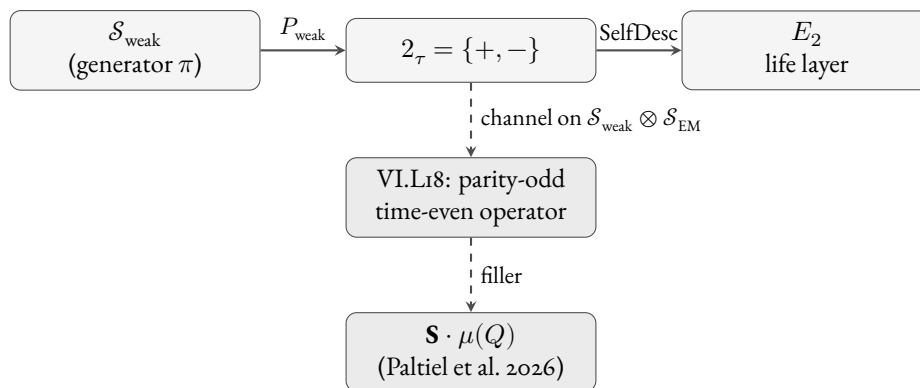
Banerjee-Ghosh et al. [1] demonstrated the *macroscopic* enantiomer-separating capability of a chiral magnetic substrate, which is the experimental base on which the vibronic-SOC programme has since been built.

### Counter-positions: classical thermodynamic amplification

A sympathetic reader will ask whether the slot claim forecloses the classical Yamagata–Salam–MacDermott thermodynamic route in which the weak-sector energy bias  $\Delta E_{LR}$ , combined with Frank-style nonlinear autocatalysis, in principle amplifies to macroscopic enantiomeric excess over geological time [7, 20]. It does not: the slot claim is agnostic between “thermal route inadequate” and “thermal route ruled out.” The classical route is regarded in the field as implausible rather than impossible; we note its main ingredients for reference and explain why they do not undermine VI.L18.

Kondepudi and Nelson [18] showed that stochastic fluctuations plus Frank-type autocatalytic networks can lift a seed bias of order  $\Delta E_{LR}/k_B T \sim 10^{-13}$  to macroscopic ee, provided the coupling constants and reaction volumes fall in a fine-tuned range and provided geological-timescale stationarity of the reaction

<sup>7</sup>The Ozturk–Sasselov sign is conditional on the terrestrial geomagnetic history of the magnetite substrate: the sign-setting input is the magnetisation direction of the ferromagnetic mineral at the time of the RAO-crystallisation event (Ozturk et al. [23], §3; Ozturk–Sasselov–Sutherland [25], “central dogma” step 2). The VI.L18 slot is sign-independent and does not determine the sign unconditionally; the conditional character is discussed in Section 9, Q3.



**Figure 1.** Slot–filler identification.<sup>6</sup> The Parity Bridge factorisation (4) determines the structural slot for the amplification channel (VI.L18, Lemma 3.4); the Paltiel operator  $\mathbf{S} \cdot \mu(Q)$  (6) occupies that slot. The dashed lines carry only the structural identification, not a derivation; see Section 5.

environment. The fine-tuning concern is what relegates this route to “implausible under realistic abiotic conditions” rather than “ruled out.” Viedma [33] later demonstrated experimental deracemisation in a purely thermodynamic system (chiral crystallisation under attrition), but that mechanism requires an initial seed bias, which is what the VI.L18 slot supplies; Viedma’s result is therefore complementary to the slot claim, not competitive with it. Klusmann and Blackmond’s eutectic amplification [17] operates on the same logic: given a seed, amplification is efficient. MacDermott and Tranter [20] provided the direct electroweak-perturbation computations of  $\Delta E_{LR}$  per proteinogenic amino acid on which the  $10^{-17}$ – $10^{-14}$  eV range is based.

In parallel, Globus and Blandford [15] have proposed that cosmic-ray-induced secondary electron spin asymmetry, rather than intramolecular CISS, is the relevant chirality-transfer channel from the weak sector to prebiotic chemistry. This is a distinct *non-intramolecular* candidate for the VI.L18 slot, and it deserves explicit mention. The slot claim in its current form is agnostic between intramolecular (Paltiel-type) and external (Globus–Blandford-type) realisations of the parity-odd, time-even channel, provided each realisation independently satisfies the VI.L18 symmetry requirements on the tensor product  $\mathcal{S}_{\text{weak}} \otimes \mathcal{S}_{\text{EM}}$ .

We note, without claiming anything stronger, that the theoretical coherence between the Panta Rhei structural argument and the vibronic CISS programme points toward a plausible research direction: tightening the VI.L18 slot from a symmetry specification to a quantitative specification by using IV.T146 ( $\sigma = C_\tau$ , all neutrinos Majorana from self-adjointness) [12, 11] to pin the matrix-element scale. We leave this to future work.

## 8. WHAT THIS DOES, AND DOES NOT, MEAN FOR BOOK VI

Book VI’s scope-discipline ledger has two entries directly relevant here:

- **VI.OP9 (homochirality derivation):** flagged SOLVED in Remark VI.R26 (rem:vi-homochirality-scope-upgrade) for the *existence-of-preference claim*, via the VI.D71–VI.T43 chain, but with two residual open questions—the sign of the preference (L vs. R), and experimental validation of a universal sign across the 20 proteinogenic amino acids.
- **Remark VI.R09 “Not claimed”:** the identification of

the amplification mechanism with the Riemann force is *conjectural*; the existence of some amplification channel is  $\tau$ -effective.

The present note upgrades the latter in a symmetry-bounded sense. The amplification channel is now realised by a *specific, independently derived* operator, the vibronic  $\mathbf{S} \cdot \mu$ ; the symmetry class required of any such operator is pinned by VI.L18, Lean-certified; and the specific mechanism occupying that class at leading order is Paltiel et al.’s result. The upgrade is from “mechanism entirely conjectural” to “mechanism plausibly filled, pending formal derivation within the framework (open question Q4).” The upgrade does not resolve VI.OP9’s residual questions about *sign*: VI.L18 is sign-independent, and neither it nor Paltiel et al.’s result determines why terrestrial life chose L over R rather than the other way around. That question is left to the Ozturk–Sasselov RAO/magnetite route, where the specific terrestrial geology of magnetite surfaces is proposed to select [23, 24] (but is also not fully resolved).

The identification does not replace the Riemann/Hodge/Poincaré conjectural identifications in the four-force picture (Book VI §16.4). It replaces only the *amplification* role—the Riemann slot—with a specific mechanism. The Hodge (double-well stabilisation) and Poincaré (topological lock-in) slots remain open to further specific identifications, as does the question of whether those slots are filled by the same physical process (unified CISS-mediated amplification-plus-stabilisation) or by separate processes (CISS amplification followed by classical autocatalytic stabilisation).

## 9. OPEN QUESTIONS AND FUTURE WORK

**Q1. Quantitative slot..** Lemma 3.4 specifies the symmetry of the amplification operator but not its matrix-element scale. Can IV.T146 ( $\sigma = C_\tau$ , Majorana neutrinos from self-adjointness) be used to pin the scale of  $\langle \psi_L | \mathbf{S} \cdot \mu | \psi_R \rangle$  from within the framework, rather than only bounding it by  $\gg \Delta E_{LR}$ ?

**Q2. Higher-rank operators..** Remark 3.5 noted that higher-rank pseudoscalar contractions exist; what are their contributions to the CISS asymmetry on which experiments have not yet distinguished them from  $\mathbf{S} \cdot \mu$ ? A direct test would be to search for ultrafast-timescale deviations from the leading-order prediction [30].

**Q3. Sign selection..** The slot is sign-independent. Why terrestrial life uses L-amino acids rather than R-amino acids is a separate question. Three candidate sign-selecting scenarios are consistent with VI.L18:

- The Ozturk–Sasselov magnetite-mediated pathway [23, 24], in which the magnetisation direction of prebiotic magnetite surfaces determines the sign of the CISS-transferred asymmetry. The sign is conditional on the terrestrial geomagnetic history at the time of the RAO-crystallisation event.
- A symmetry-breaking bifurcation within the double-well landscape of Book VI’s Hodge stabilisation (Book VI §16.4, Hodge slot), which would make the sign a frozen accident rather than a determined outcome.
- The Globus–Blandford cosmic-ray pathway [15], in which longitudinally polarised secondary electrons from cosmic-ray muon showers inherit a definite handedness from parity violation in muon decay, and that handedness transfers to prebiotic chemistry via the same parity-odd, time-even channel class as the intramolecular CISS mechanism. In this picture the sign is set by the kinematics of the weak-decay chain itself and is therefore universal across any planet sampling the same cosmic-ray population.

The three possibilities are distinguishable empirically. If any extraterrestrial biochemistry is ever discovered and found to use L-amino acids, scenario (a) or (c) is favoured over (b); if different worlds consistently use the same sign, (c) is favoured over (a); if they use different signs, (b) is favoured; if they use R across the board, (a) is favoured in its R-magnetite variant, and (c) is ruled out.

**Q4. Formal derivation within the framework..** The present note identifies the Paltiel mechanism with the slot by symmetry match. A formal derivation of  $V_{\text{SOC}}^{\text{chiral}} \supset \mathbf{S} \cdot \mu$  from the Ko–K6 axioms via the chain  $\sigma = C_{\tau}$  (IV.T146)  $\rightarrow$  Parity Bridge (VI.T01)  $\rightarrow$  polarity propagation (VI.D71) is an open research direction. Such a derivation, if successful, would upgrade the slot–filler identification from symmetry-level to mechanism-level and would constitute an independent derivation of the CISS operator from within the Panta Rhei framework.

## 10. CONCLUSION

Panta Rhei’s Parity Bridge Theorem (VI.T01) placed on the public record, with Zenodo deposit 10.5281/zenodo.19553667 of 2026-04-13T11:32:53Z, the structural requirement that a non-thermal, parity-odd, time-even, weak- $\otimes$ -EM amplification channel must exist between the weak-sector chirality seed and biological homochirality. That requirement is formalised as the  $\tau$ -effective lemma VI.L18 (Kinetic Pseudoscalar Channel), Lean-certified in `TauLib.BookVI.LifeCore.ParityBridge`. Nine days after that deposit, on 2026-04-22, Paltiel et al. published the specific operator—the vibronic  $\mathbf{S} \cdot \mu(Q)$  matrix element—that fills the slot. The two records are independent: the Paltiel paper was submitted to *Science Advances* on 2025-10-08, six months before the Panta Rhei deposit, and the two research lines have no prior contact.

The identification is symmetry-level and bounded. Panta Rhei’s priority is on the structural slot, not on the mechanism that occupies it; Paltiel et al.’s original work is the derivation of the mechanism, which the Panta Rhei framework does not

duplicate. The identification is falsifiable along three clearly specified axes (§6), any of which would force a revision of VI.L18 or of the slot–filler match.

We offer this note as a calibrated record of the theoretical-coherence event, in the hope that the priority ledger it documents is useful to the CISS and homochirality communities as an independent, prior, and structurally-derived motivation for the line of work that Paltiel et al. have now made specific.

## ACKNOWLEDGEMENTS

We acknowledge Paltiel et al.’s independent and prior work on the vibronic spin–orbit coupling operator, and the Panta Rhei Research Program’s Physics Ledger and TauLib Formal Library teams for enforcing the scope discipline that made the slot claim auditable in the first place.

## A. THE LEAN CERTIFICATE FOR VI.L18

The structural content of Lemma 3.4 is Lean-certified in the module `TauLib.BookVI.LifeCore.ParityBridge` (file `lean4/TauLib/TauLib/BookVI/LifeCore/ParityBridge.lean`) with the following theorem signature:

```
theorem kinetic_pseudoscalar_channel :
  kinetic_channel.parity_odd = true  $\wedge$ 
  kinetic_channel.time_even = true  $\wedge$ 
  kinetic_channel.sector_product = 2  $\wedge$ 
  kinetic_channel.non_thermal = true  $\wedge$ 
  polarity_functional.nontrivial_count =
    1  $\wedge$ 
  polarity_propagation.sign_preserved =
    true  $\wedge$ 
  chirality_seed.va_coupling_pct = 100
:= (rfl, rfl, rfl, rfl, rfl, rfl, rfl)
```

The invariants of the Kinetic–Pseudoscalar–Channel structure—parity-odd, time-even, weak- $\otimes$ -EM tensor product, non-thermal—are proved by `rfl` from the structure fields. The dependencies on `polarity_functional.nontrivial_count=1` (VI.L01), `polarity_propagation.sign_preserved=true` (VI.T41), and `chirality_seed.va_coupling_pct=100` (VI.D72) link the lemma to the rest of the Parity Bridge infrastructure already Lean-certified in the same module.

Build status at the time of writing: 834 jobs in the `ParityBridge.lean` module, 1270 jobs across the full `TauLib` library, 0 errors, 0 sorry.

## B. REGISTRY ENTRY

The VI.L18 registry entry (`registry/book6_registry.jsonl`) carries the following fields:

- `id`: VI.L18
- `name`: Kinetic Pseudoscalar Channel
- `type`: lemma
- `part`: 2, chapter: 16
- `depends_on`: {VI.L01, VI.T01, VI.D71, VI.D72, VI.T41}

- lean\_module: TauLib.BookVI.LifeCore.ParityBridge
- lean\_name: Tau.BookVI.ParityBridge.kinetic\_pseudoscalar\_channel
- formalization: formalized
- scope: tau-effective

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