

Article

From Fibonacci Anyons to B-DNA and Microtubules via Elliptic Curves

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Abstract

By imposing finite order constraints on Fibonacci anyon braid relations, we construct the finite quotient $G = \mathbb{Z}_5 \rtimes 2I$, where $2I$ is the binary icosahedral group. The Gröbner basis decomposition of its $SL(2, \mathbb{C})$ character variety yields elliptic curves whose L-function derivatives $L'(E, 1)$ remarkably match fundamental biological structural ratios. Specifically, we demonstrate that the Birch–Swinnerton-Dyer conjecture’s central quantity: the derivative $L'(E, 1)$ of the L-function at 1 encodes critical cellular geometries: the crystalline B-DNA pitch-to-diameter ratio ($L'(E, 1) = 1.730$ matching $34 \text{ Å} / 20 \text{ Å} = 1.70$), the B-DNA pitch to major groove width ($L' = 1.58$) and, additionally, the fundamental cytoskeletal scaling relationship where $L'(E, 1) = 3.570 \approx 25/7$, precisely matching the microtubule-to-actin diameter ratio. This pattern extends across the hierarchy $\mathbb{Z}_5 \rtimes 2P$ with $2P \in \{2O, 2T, 2I\}$ (binary octahedral, tetrahedral, icosahedral groups), where character tables of $2O$ explain genetic code degeneracies while $2T$ yields microtubule ratios. The convergence of multiple independent mathematical pathways on identical biological values suggests that evolutionary optimization operates under deep arithmetic-geometric constraints encoded in elliptic curve L-functions. Our results position the BSD conjecture not merely as abstract number theory, but as encoding fundamental organizational principles governing cellular architecture. The correspondence reveals arithmetic geometry as the mathematical blueprint underlying major biological structural systems, with Gross–Zagier theory providing the theoretical framework connecting quantum topology to the helical geometries that are essential for life.



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1. Introduction

For more than a century, scientists have searched for a rigorous mathematical framework that is capable of unifying the geometry of living matter with the discrete laws that govern physical reality. Early pioneers such as D’Arcy Thompson, Nicolas Rashevsky, and Alan Turing demonstrated that differential geometry, mathematical biophysics, and reaction–diffusion theory could reproduce many morphogenetic motifs [1–3]. Subsequent decades witnessed the introduction of fractal geometry into genomics [4,5], knot- and link-theoretic analyses of DNA topology and supercoiling [6–8], and continuum mechanical models of cytoskeletal patterning [9].

Despite these advances, a unifying mathematical principle capable of predicting quantitative biomolecular dimensions has remained elusive.

The present work addresses a fundamental question: why are helical geometries essential for life? Earlier approaches offered valuable but partial insights [10–12]. In [10], symmetry and morphological patterning are attributed to external physical constraints that confer a selective advantage at multiple scales. In [11], the prevalence of mathematical regularity in biology is linked to the intrinsic mathematical properties of molecules and their interaction potentials. In [12], mathematical structures are viewed as ensuring informational parsimony in genetic encoding. These perspectives capture complementary aspects of biological order, but they remain largely phenomenological and lack a predictive algebraic framework.

Two modern mathematical revolutions now supply the missing structure. *Quantum topology*, through anyons, modular tensor categories, and topological quantum computation, has shown how braided quasiparticles generate robust, finite-dimensional state spaces protected by topology [13,14]. *Arithmetic geometry*, through the Modularity Theorem and the Birch–Swinnerton-Dyer and Gross–Zagier conjectures, has revealed profound links between prime number statistics and the geometry of elliptic curves [15–18]. In the present paper, we demonstrate that these two domains intersect at precisely the mesoscopic scale of cellular architecture: finite quotients of the Fibonacci anyon braid group generate $SL(2, \mathbb{C})$ character varieties whose elliptic components yield L -function derivative $L'(E, 1)$ matching to experimental precision, key biological ratios—B-DNA pitch-to-diameter and major groove width—as well as microtubule and cytoskeletal dimensions.

1.1. A Novel Quantum–Arithmetic Framework for Theoretical Biology

Our approach represents a conceptual shift in mathematical biology. Rather than imposing external mathematical models on biological phenomena, we show that the intrinsic constraints of quantum topology naturally generate the arithmetic–geometric structures—elliptic curves and their L -functions—that encode biological optimization. This process unfolds through the following rigorous pipeline:

1. Quantum–topological origin: We begin with Fibonacci anyons [19], fundamental excitations in $SU(2)_3$ topological quantum field theory, whose braid representations act on infinite-dimensional spaces of quantum amplitudes.
2. Finite quotient construction: Imposing both finite order and standard braid relations yields finite groups $G = \mathbb{Z}_5 \rtimes 2P$, where $2P$ is a binary polyhedral group (tetrahedral, octahedral, or icosahedral).
3. Character variety decomposition: The $SL(2, \mathbb{C})$ character varieties of these groups decompose—via Gröbner basis analysis—into components that include rank-1 elliptic curves.
4. Arithmetic–biological correspondence: The derivatives $L'(E, 1)$ of the associated elliptic L -functions correspond, within a few percents, to fundamental biological ratios, revealing that evolutionary optimization operates under arithmetic–geometric constraints.

This pipeline shows that biological organization is not merely geometric but arithmetic–topological in nature: evolution appears to explore discrete spaces governed by number-theoretic optimization, a process mathematically captured by the Birch–Swinnerton-Dyer and Gross–Zagier frameworks.

1.2. Structure and Main Contributions

The paper establishes the theoretical and empirical foundations of quantum–arithmetic biology through three complementary analyses.

Section 2: Experimental Evidence reviews precise helical parameters of two paradigmatic biological systems—B-form DNA and microtubules—that serve as empirical benchmarks for our theory. We synthesize data from X-ray diffraction, crystallography, solution-

state, and cryo-EM studies to fix reference ratios: crystalline B-DNA pitch-to-diameter (1.70), hydrated B-DNA (1.40), pitch-to-major groove width (1.58), and microtubule structural ratios including GDP-tubulin rings (1.58), outer-to-inner diameter (1.72), and microtubule-to-actin diameter (3.57). These measurements, reproducible within 2–5%, set stringent quantitative targets for any proposed mathematical correspondence.

Section 3: Mathematical Framework formalizes the link between elliptic curves, L -functions, and biological optimization. We focus on rank-1 elliptic curves, for which $L'(E, 1)$ captures the balance of local and global constraints expressed in the Birch–Swinnerton-Dyer formula. Through Gross–Zagier theory, these derivatives are interpreted as canonical heights of Heegner points over imaginary quadratic fields, implying that biological helices operate at the intersection of modular curve geometry and number-field arithmetic.

Section 5: The Hierarchy $\mathbb{Z}_5 \rtimes 2P$ constructs the full progression from Fibonacci anyons to finite groups and their biological correspondences. Each group in the hierarchy— $\mathbb{Z}_5 \rtimes 2T$, $\mathbb{Z}_5 \rtimes 2O$, and $\mathbb{Z}_5 \rtimes 2I$ —produces character varieties whose elliptic components match specific biological systems: $2T$ corresponds to microtubule protofilament ratios, $2O$ encodes genetic code degeneracies and hydrated DNA geometry, and $2I$ captures the crystalline B-DNA ratio. The associated optimal imaginary quadratic fields ($\mathbb{Q}(\sqrt{-3})$, $\mathbb{Q}(i)$, etc.) naturally reproduce the hexagonal and rectangular symmetries observed in living structures.

The convergence of multiple mathematical pathways toward identical biological ratios demonstrates that evolution operates within arithmetic–geometric constraint spaces. We thus propose that the Birch–Swinnerton-Dyer and Gross–Zagier theories provide not only a mathematical formalism for number theory but also a predictive language for the architecture of life. Table 1 summarizes the principal correspondences.

Sections 6 and 7 discuss the broader implications, from evolutionary optimization to quantum information, and outline the future integration of arithmetic geometry with topological quantum computation in biological systems.

Table 1. Arithmetic–biophysical correspondences as detailed in the main text. Labels follow the LMFDB database [20]. The convergence of 200b2 and 184a1 on the same ratio through distinct mathematical pathways exemplifies overdetermined biological constraints. The hierarchy further shows that DNA arithmetic geometry encodes the blueprint for cytoskeletal architecture, while large bad primes (e.g., 337) signal higher-order structure.

Mathematical Origin	E-Curve	$L'(E, 1)$	Bad Primes	Biophysical Ratio	Exp.
$\mathbb{Z}_5 \rtimes 2T$ (120, 15)	880b2	1.869	(2, 5, 11)	MT outer/inner diam.	1.72
	200b2	1.088	(2, 5)	PF-thinning ratio	1.20
m003(−3, 1)	184a1	1.088	(2, 23)	PF-thinning ratio	1.20
$\mathbb{Z}_5 \rtimes 2O$ (240, 105)	300a1	1.384	(2, 3, 5 ²)	B-DNA hydrated p/d	1.40
$\mathbb{Z}_5 \rtimes 2I$ (600, 54)	485b1	1.730	(5, 97)	B-DNA crystalline p/d	1.70
	715b1	1.579	(5, 11, 13)	B-DNA p/Mgwidth	1.54
MT substructure	16176u1	3.570	(2, 3, 337)	MT/actin diameter	3.57

2. Experimental Evidence: Biological Helical Geometries

This section establishes the experimental foundation for our theoretical claims by documenting the precise helical geometric parameters of the two key biological information-processing systems: B-form DNA and microtubules. These measurements provide the empirical targets that our elliptic curve L -function derivatives must match.

2.1. B-Form DNA Helical Parameters

We define the helical *pitch* (P) as the axial rise for one complete 360° turn, the *diameter* (D) as the distance across the outer van der Waals surface (unless otherwise specified), and the critical ratio $R = P/D$ that characterizes the helical geometry.

2.1.1. X-Ray Fiber Diffraction

The canonical measurements derive from X-ray diffraction of moderately hydrated, axially oriented DNA fibers, pioneered by Franklin and Wilkins in 1953 [21]. The spacing of meridional layer lines ($\Delta s = 0.0294 \text{ \AA}^{-1}$) directly yields the axial pitch $P = 1/\Delta s \approx 34 \text{ \AA}$ (approximately 10 base pairs per turn). The positions of equatorial intensity maxima correspond to the first zero of the J_0 Bessel function for a cylinder of van der Waals radius $\approx 10 \text{ \AA}$, giving an outer diameter $D \approx 20 \text{ \AA}$.

These independent measurements combine to yield the textbook pitch-to-diameter ratio:

$$R = \frac{P}{D} \approx \frac{34}{20} = 1.70 \pm 0.05$$

This value has been reproduced within 2% by subsequent fiber and crystal studies [22,23].

Another important length that characterizes B-DNA is the major groove width whose value is approximately $Mgw = 22 \text{ \AA}$. This leads to the ratio $P/Mgw \approx 1.54$ with a similar uncertainty range to $\frac{P}{D}$.

2.1.2. Solution State Measurements

In free solution, DNA adopts its intrinsic twist, unperturbed by crystal packing forces. Depew and Wang (1975) used topoisomerase I to fully relax covalently closed plasmids and analyzed the resulting topoisomer distribution [24]. At 0.1 M of monovalent salt, the mean linking number corresponded to 10.45 ± 0.05 bp per turn. Multiplying by the canonical rise per base step (0.335 nm) gives a solution pitch of $P \approx 35 \text{ \AA}$.

Hydrodynamic and small-angle X-ray scattering experiments on fully hydrated duplexes indicate an *effective hydrated diameter* of $D \approx 25 \pm 2 \text{ \AA}$ [25]. Using this diameter, the pitch-to-diameter ratio in free solution is

$$R = \frac{P}{D} \approx \frac{35}{25} = 1.40 \pm 0.05.$$

Single-molecule techniques likewise report helical repeats in the range of 10.4–10.6 bp per turn under physiological conditions [26,27].

2.1.3. High-Resolution Crystal Structures

X-ray crystallography provides atomic-level precision for B-DNA geometry. The archetypal Drew–Dickerson dodecamer (CGCGAATTCGCG) exhibits an average axial rise of $3.38 \text{ \AA}$ per base step and $\approx 36^\circ$ twist, yielding $P \approx 10 \times 3.38 = 33.8 \text{ \AA}$ [28]. The outer phosphate-to-phosphate distance ranges from 19 to $21 \text{ \AA}$, giving $R = 1.6$ – 1.8 .

A comprehensive survey of 57 high-resolution B-DNA structures showed that P clusters around 33 – $34 \text{ \AA}$ while D varies from 18 to $21 \text{ \AA}$ in a sequence-dependent manner, maintaining a global mean of $R = 1.70 \pm 0.05$ [29].

2.1.4. Hydrodynamic Measurements

Solution hydrodynamics probes the effective DNA size including the first hydration shell through sedimentation coefficients, intrinsic viscosity, and diffusion constants fitted to rod-like models [30,31]. Modern analysis of T4 and calf-thymus DNA yields Stokes diameters of $D = 22$ – $26 \text{ \AA}$ [29]. Combined with the fiber diffraction pitch, this gives the following equation:

$$R = \frac{P}{D} \approx \frac{34.5}{24} = 1.3$$
– 1.5

The lower ratio reflects the inclusion of structured water and mobile counter-ions in the hydrodynamic radius. Dynamic light scattering and fluorescence correlation spectroscopy confirm these values [32,33].

2.2. Microtubule Structural Parameters

Microtubules present several geometric relationships that are relevant to our theory, involving both structural ratios and cytoskeletal scaling relationships.

2.2.1. Basic Dimensions

Cryo-electron microscopy (cryo-EM) and X-ray diffraction converge on an outer diameter of $D_{\text{out}} = 25 \pm 1$ nm and a lumen diameter of $D_{\text{in}} = 14\text{--}15$ nm for canonical 13-protofilament microtubules [34–36].

The outer-to-inner diameter ratio is as follows: $R_{\text{outer/inner}} = \frac{D_{\text{out}}}{D_{\text{in}}} = \frac{25}{14.5} \approx 1.72$.

2.2.2. Protofilament-Thinning Ratio

Reducing the protofilament number narrows the microtubule tube. Taxol-stabilized 12-protofilament microtubules contract to a 22 ± 0.5 nm outer diameter [36], whereas *C. elegans* 11-protofilament microtubules measure at 19.9 ± 0.5 nm [37].

Defining the thinning factor,

$$\gamma_{\text{PF}} = \frac{D_{13}}{D_n}, \quad n \in \{11, 12\}$$

we obtain $\gamma_{13 \rightarrow 12} = 1.14$ and $\gamma_{13 \rightarrow 11} = 1.26$; hence, we adopt $\gamma_{\text{PF}} = 1.2 \pm 0.1$ for subsequent comparisons.

2.2.3. Microtubule-to-Actin Diameter Ratio

Taking $D_{\text{actin}} = 7 \pm 1$ nm for F-actin filaments [38], the fundamental cytoskeletal scaling ratio is as follows:

$$\frac{D_{\text{MT}}}{D_{\text{actin}}} = \frac{25 \text{ nm}}{7 \text{ nm}} \approx 3.57$$

2.3. Summary of Experimental Targets

The experimental values summarized in Tables 2 and 3 provide the empirical benchmarks against which we will compare the L -function derivatives of elliptic curves emerging from our quantum topological analysis. The precision required—matching to within a few percents—demands that any proposed mathematical correspondence be more than coincidental, suggesting deep underlying principles connecting arithmetic geometry to biological optimization.

Table 2. Experimental helical and structural ratios for biological systems. For DNA, P = pitch and D = diameter. For microtubules, various structural ratios are compared as indicated.

System/Method	P or D (Å or nm)	D (Å or nm)	Ratio
B-DNA Helical Parameters			
Fiber diffraction	34.0 ± 0.3 Å	20.0 ± 0.5 Å	1.70 ± 0.05
Solution state	34.5 ± 0.2 Å	24.0 ± 0.5 Å	1.40 ± 0.05
Crystallography	33.8 ± 0.3 Å	20 ± 1 Å	1.69 ± 0.09
Hydrodynamics	34.5 ± 0.5 Å	24 ± 2 Å	1.44 ± 0.12
Microtubule Structural Parameters			
Outer/inner diameter	25 ± 1 nm	14.5 ± 0.5 nm	1.72 ± 0.08
MT/actin diameter	25 ± 1 nm	7 ± 1 nm	3.57 ± 0.51

Table 3. Detailed experimental dimensions used in this study.

Quantity	Value	Reference
Microtubule Dimensions		
Outer diameter (13-pf)	25 ± 1 nm	[34,35]
Inner diameter (13-pf)	14–15 nm	[34,35]
Outer diameter (12-pf)	22 ± 0.5 nm	[36]
Outer diameter (11-pf)	19.9 ± 0.5 nm	[37]
Actin Filaments		
F-actin diameter	7 ± 1 nm	[38]

3. Elliptic Curves and Their Arithmetic

This section introduces, in a self-contained way, the minimal concepts from arithmetic geometry used in the rest of the paper.

An elliptic curve E over the rational numbers $\mathbb{Q}$ is a smooth projective curve of genus 1, equipped with a rational point serving as the group identity. It can be written in *Weierstrass form* as

$$E : y^2 = x^3 + ax + b, \quad (1)$$

where $a, b \in \mathbb{Q}$ and the *discriminant*

$$\Delta = -16(4a^3 + 27b^2)$$

is nonzero.

The discriminant $\Delta \neq 0$ guarantees that the cubic polynomial in x has distinct roots, i.e., the curve is nonsingular. Geometrically, $E(\mathbb{C})$ is a torus (a compact Riemann surface of genus 1). The phrase *projective curve* means that we homogenize the above equation and view its solutions in the projective plane $\mathbb{P}^2$, which adds one point at infinity.

The set of rational points $E(\mathbb{Q})$ forms a finitely generated abelian group by the chord–tangent law:

$$E(\mathbb{Q}) \cong E(\mathbb{Q})_{\text{tors}} \oplus \mathbb{Z}^r, \quad (2)$$

where $E(\mathbb{Q})_{\text{tors}}$ is a finite torsion subgroup and $r = \text{rank}(E)$ is the *Mordell–Weil rank*. The rank r counts the number of independent rational points of infinite order, and its value is the central unknown in the Birch–Swinnerton-Dyer conjecture (BSD).

3.1. Good and Bad Primes; Local Factors

For each prime p , one may reduce the coefficients of E modulo p and obtain a curve of $\tilde{E}/\mathbb{F}_p$. If $\tilde{E}$ is nonsingular, the prime p is said to be *good*; otherwise, it is *bad*. Equivalently, p is bad if it divides the discriminant Δ . The finite set of bad primes is encoded by the *conductor* $N_E = \prod p^{f_p}$, whose exponents f_p quantify the severity of the singular reduction.

At a good prime p , define the *Frobenius trace*

$$a_p = p + 1 - \#E(\mathbb{F}_p),$$

where $\#E(\mathbb{F}_p)$ counts the number of points modulo p (including the point at infinity). This integer measures how far the actual number of points deviates from the expected $p + 1$. The Hasse bound $|a_p| \leq 2\sqrt{p}$ follows from the Riemann hypothesis for curves over finite fields.

3.2. The L -Function of an Elliptic Curve

The global L -function of $E/\mathbb{Q}$ is defined as the Euler product:

$$L(E, s) = \prod_{p \text{ good}} (1 - a_p p^{-s} + p^{1-2s})^{-1} \prod_{p \text{ bad}} L_p(E, s)^{-1}, \quad (3)$$

where each local factor $L_p(E, s)$ encodes the contribution of the reduction at p . For good primes, the quadratic factor above arises from the characteristic polynomial of Frobenius on the Tate module. For bad primes, one uses simpler linear factors according to the reduction type (additive or multiplicative).

The product converges for $\Re(s) > 3/2$ and extends analytically to the entire complex plane. The *Modularity Theorem* [15] ensures that $L(E, s)$ equals the L -function of a weight 2 modular form $f_E(q)$ of level N_E , and hence satisfies a functional equation

$$\Lambda(E, s) = N_E^{s/2} (2\pi)^{-s} \Gamma(s) L(E, s) = w_E \Lambda(E, 2-s),$$

with sign $w_E = \pm 1$. This modularity result is the analytic backbone allowing the precise computation of $L(E, s)$ and its derivatives at $s = 1$.

3.3. The Birch–Swinnerton-Dyer Conjecture

The BSD conjecture relates the rank r of $E(\mathbb{Q})$ to the behavior of $L(E, s)$ at $s = 1$:

$$r = \text{ord}_{s=1} L(E, s).$$

In other words, the order of vanishing of the L -function equals the number of independent rational points of infinite order.

The conjecture also predicts that the leading coefficient in the Taylor expansion

$$L(E, s) = c_r (s-1)^r + \dots$$

is given by

$$c_r = \frac{\Omega_E \text{Reg}(E) |\text{Sha}(E)| \prod c_p}{|E(\mathbb{Q})_{\text{tors}}|^2},$$

where Ω_E is the real period, $\text{Reg}(E)$ is the regulator (determinant of the height pairing of generators), $\text{Sha}(E)$ is the Tate–Shafarevich group, and c_p are Tamagawa numbers. All quantities on the right are, in principle, computable. For curves of analytic rank 1 (i.e., $L(E, 1) = 0$ but $L'(E, 1) \neq 0$), $L'(E, 1)$ is proportional to the canonical Néron–Tate height of a rational point. This is the regime we focus on because it yields a single real invariant $L'(E, 1)$ that can be compared to biological ratios.

3.4. Gross–Zagier Formula and Heights

For modular elliptic curves of analytic rank 1, the celebrated Gross–Zagier theorem expresses $L'(E, 1)$ as

$$L'(E, 1) = \frac{c_E}{\Omega_E} \langle P_E, P_E \rangle,$$

where $\langle P_E, P_E \rangle$ is the canonical height of a Heegner point on E and c_E is an explicit constant depending on the level N_E and the discriminant of the corresponding imaginary quadratic field. This formula provides a bridge between analysis (the derivative $L'(E, 1)$) and arithmetic geometry (heights of rational or algebraic points). In the present paper, we interpret $L'(E, 1)$ as an arithmetic measure of structural stability or self-consistency, which we compare with the observed dimensionless ratios in biological forms.

To make the exposition verifiable, all curves used in computations are given explicitly by their coefficients (a, b) , discriminant Δ , conductor N_E , and a list of Frobenius traces a_p for small primes. Readers can reproduce the corresponding $L'(E, 1)$ values using mathematical softwares such as Magma or Pari/GP or use data of the LMFDB database.

3.5. Summary of Mathematical Framework

We have thus fixed the minimal background required:

- Elliptic curve $E/\mathbb{Q}$ in Weierstrass form, smooth $\Leftrightarrow \Delta \neq 0$;
- Group of rational points $E(\mathbb{Q})$, rank r , torsion subgroup;
- Good/bad primes, conductor N_E , and Frobenius traces a_p ;
- Modular L -function $L(E, s)$, analytic continuation, and derivative $L'(E, 1)$;
- Gross–Zagier relation linking $L'(E, 1)$ to canonical heights.

All these ingredients are now available to establish the arithmetic–biological correspondence in the following sections.

4. Elliptic Invariants and Biological Optimization

We now turn from formal arithmetic definitions to their biological interpretation, viewed as an empirical synthesis preceding the finite-group hierarchy of Section 5.

We propose that for appropriately chosen rank-1 elliptic curves, the quantities $L'(E, 1)$ encode *optimal geometric ratios* governing biological information-processing systems. The Birch–Swinnerton-Dyer relation expresses a balance of constraints—periods, regulators, Tamagawa factors, and global compatibilities—that mirrors biological optimization between scale, structure, and coherence. In this sense, the arithmetic architecture of an elliptic curve can be viewed as a minimal model of biological efficiency.

Arithmetic–Geometric Optimization.

The BSD formula embodies scale invariance through the real period Ω_E , configurational complexity via the canonical height h_E , local constraints from Tamagawa numbers c_p , and global consistency through the Tate–Shafarevich group $\text{Sha}(E)$. Together they form a self-consistent optimization scheme, suggesting that evolution may have discovered configurations naturally satisfying these arithmetic symmetries.

Classical–Quantum Correspondence. Biological ratios empirically match $L'(E, 1)$ rather than simpler quantities like period ratios $|\omega_1/\omega_2|$. This distinction reflects the crossing from classical to quantum domains: period ratios describe the geometry of complex tori, while derivatives of L -functions incorporate quantum-arithmetic data (regulators, $\text{Sha}(E)$, c_p). Hence, living systems may operate near this classical–quantum boundary, optimizing not merely geometry but the deeper discrete relations that encode information.

Gross–Zagier Perspective. The Gross–Zagier theorem links $L'(E, 1)$ to canonical heights of Heegner points arising from imaginary quadratic fields. This provides a geometric picture in which biological helices—often displaying near-hexagonal symmetries reminiscent of $\mathbb{Q}(\sqrt{-3})$ —can be viewed as macroscopic analogues of these arithmetic configurations on modular curves.

Rank-1 Specificity. Restricting to rank-1 curves is natural: such curves possess exactly one independent rational point of infinite order, reflecting systems that optimize a single dominant geometric parameter while satisfying subsidiary constraints. Moreover, the derivative $\{L'(E, 1)\}$ captures the critical scaling at $\{s = 1\}$, evocative of biological self-organization near transition thresholds.

Transition. The next section develops how specific finite-group constructions, arising from braid and modular representations of $SU(2)_k$, generate these same rank-1 elliptic curves and their characteristic $\{L'(E, 1)\}$ values. This establishes the bridge between the continuous

arithmetic geometry discussed here and the discrete topological symmetries governing the hierarchy of finite groups.

5. The Hierarchy of Finite Groups $\mathbb{Z}_5 \rtimes 2P$ with $2P \in \{2I, 2O, 2T\}$

Context and notation. We pass from the elliptic–biological synthesis (Section 4) to the discrete symmetry side. Here, $2P$ denotes a binary polyhedral group: $2I \simeq \text{SL}(2, 5)$ (binary icosahedral), $2O$ (binary octahedral), and $2T$ (binary tetrahedral). The semidirect product $\mathbb{Z}_5 \rtimes 2P$ is taken with the standard faithful action of $2P$ on $\mathbb{Z}_5^\times$. This section keeps your constructions intact and only streamlines exposition and transitions.

5.1. From Fibonacci Anyons to the Finite Quotient $G = \mathbb{Z}_5 \rtimes 2I$

The Fibonacci anyon model arises from the unitary modular tensor category associated with $\text{SU}(2)_3$ [13,14,39]. This category contains two simple objects: the vacuum $\mathbf{1}$ and a non-trivial object τ satisfying the fusion rule

$$\tau \otimes \tau \cong \mathbf{1} \oplus \tau. \quad (4)$$

The braiding and fusion structure is encoded in the R - and F -matrices. For the three-strand braid group B_3 acting on $\text{Hom}(\tau^{\otimes 3}, \tau)$ (a two-dimensional space), the generators σ_1, σ_2 are represented as follows:

$$\sigma_1 = R, \quad \sigma_2 = FR^{-1}F, \quad (5)$$

with

$$R = \begin{pmatrix} e^{-4i\pi/5} & 0 \\ 0 & e^{-2i\pi/5} \end{pmatrix}, \quad F = \begin{pmatrix} \phi^{-1} & \phi^{-1/2} \\ \phi^{-1/2} & -\phi^{-1} \end{pmatrix}, \quad (6)$$

where $\phi = (1 + \sqrt{5})/2$ is the golden ratio. These matrices satisfy

$$\sigma_1^5 = \sigma_2^5 = \text{id}, \quad \text{but } \sigma_1\sigma_2\sigma_1 \neq \sigma_2\sigma_1\sigma_2, \quad (7)$$

and the group $\langle \sigma_1, \sigma_2 \rangle$ has a dense image (in particular, it is infinite).

5.2. Construction of the Finite Quotient

We now impose the braid relation to close the image and retain the essential icosahedral geometry.

5.2.1. The Finite Group $\mathbb{Z}_5 \rtimes \text{SL}(2, 5)$

Consider

$$G_{\text{fib}} := \langle \sigma_1, \sigma_2 \mid \sigma_1^5 = \sigma_2^5 = \text{id}, \sigma_1\sigma_2\sigma_1 = \sigma_2\sigma_1\sigma_2 \rangle. \quad (8)$$

Adding the braid relation to the order-5 constraints yields a finite group. This group is isomorphic to $\mathbb{Z}_5 \rtimes \text{SL}(2, 5)$, i.e., to $\mathbb{Z}_5 \rtimes 2I$, known in the SmallGroups library as (600, 54). (Reminder: $\text{SL}(2, 5) \cong 2I$, the binary icosahedral group.)

5.2.2. Representation over Number Fields

G_{fib} admits a faithful two-dimensional representation over the cyclotomic field $\mathbb{Q}(\zeta_5)$ with $\zeta_5 = e^{2\pi i/5}$, embeddable into $\text{SL}(2, \mathbb{C})$. This makes character-variety computations directly accessible.

5.3. Character Variety and Gröbner Basis Decomposition

The character variety $\mathcal{X}(G_{\text{fib}}, \text{SL}(2, \mathbb{C}))$ parametrizes conjugacy classes of $\text{SL}(2, \mathbb{C})$ representations [40–42]. Using computational algebraic geometry (Gröbner bases), its structure can be determined explicitly.

5.3.1. Trace Coordinate System

For a two-generator presentation $G_{\text{fib}} = \langle \sigma_1, \sigma_2 \rangle$, set

$$x = \text{tr}(\sigma_1), \quad y = \text{tr}(\sigma_2), \quad z = \text{tr}(\sigma_1 \sigma_2). \quad (9)$$

Classical $\text{SL}(2, \mathbb{C})$ trace identities (Cayley–Hamilton consequences) imply polynomial relations among x, y, z , e.g.,

$$\text{tr}(AB) + \text{tr}(AB^{-1}) = \text{tr}(A) \text{tr}(B), \quad (10)$$

$$\text{tr}(ABA^{-1}B^{-1}) = \text{tr}(A)^2 + \text{tr}(B)^2 + \text{tr}(AB)^2 - \text{tr}(A)\text{tr}(B)\text{tr}(AB) - 2, \quad (11)$$

with $A = \rho(\sigma_1)$, $B = \rho(\sigma_2)$. Imposing $\sigma_i^5 = \text{id}$ and the braid relation gives explicit polynomial constraints in (x, y, z) .

5.3.2. Primary Decomposition

The character curve factors as [43]

$$\mathcal{C} = (y - 2) \cdot (y^2 + y - 1) \cdot (zy^2 - 2y^2 - yz - 2y - z + 2) \cdot (\text{Ell}_1) \cdot (\text{Ell}_2), \quad (12)$$

where

- $(y - 2)$ corresponds to reducible representations;
- $(y^2 + y - 1) = 0$ captures the golden-ratio constraint from the Fibonacci structure;
- $zy^2 - 2y^2 - yz - 2y - z + 2 = 0$ is rational (genus 0);
- Ell_1 and Ell_2 are elliptic components.

5.3.3. Elliptic Curve Extraction

The elliptic components admit the models

$$\text{Ell}_1 : yz^2 + z^3 - y^2 - 2yz - z^2 - z + 2 = 0, \quad (13)$$

$$\text{Ell}_2 : z^4 - z^3 - y^2 - 2z^2 - y + 3z = 0. \quad (14)$$

In minimal Weierstrass form, one obtains the following, see Table 4:

- $\text{Ell}_1 \sim y^2 + y = x^3 - 2x$ (LMFDB label 485b1), with $L'(E, 1) \approx 1.72979$;
- $\text{Ell}_2 \sim y^2 + y = x^3 + x^2 - 5x + 6$ (LMFDB label 715b1), with $L'(E, 1) \approx 1.57871$.

5.4. Gross–Zagier Theory and the Optimal Quadratic Field

For 485b1 (conductor $N=5 \cdot 97$), Gross–Zagier theory selects an imaginary quadratic field $K = \mathbb{Q}(\sqrt{-D})$ satisfying the Heegner hypothesis (all primes dividing N split in K). Testing $D = 3$ yields $K = \mathbb{Q}(\sqrt{-3})$, with splitting at 5 and 97, class number $h(-3) = 1$, and a unit group of order 6.

Applying Gross–Zagier, we obtain the following:

$$L'(E/\mathbb{Q}(\sqrt{-3}), 1) = \frac{8\pi^2 \sqrt{3}}{36 \cdot \Omega_E} \hat{h}(P_{\sqrt{-3}}), \quad (15)$$

where $P_{\sqrt{-3}}$ is the Heegner point and $\hat{h}$ is the canonical height. The field $\mathbb{Q}(\sqrt{-3}) = \mathbb{Q}(\omega)$ (Eisenstein integers) offers a natural hexagonal interpretation aligned with B-DNA crystalline packing and the approach to $\sqrt{3} \approx 1.732$.

Remark. This viewpoint connects naturally to rigid local systems and the geometric Langlands program: the finite quotient $G_{\text{fib}} = \mathbb{Z}_5 \rtimes 2I$ yields rigid monodromies; elliptic

components of $\mathcal{X}(G_{\text{fib}}, \text{SL}(2, \mathbb{C}))$ pick out arithmetic specializations that are compatible with Gross–Zagier.

Table 4. Arithmetic properties of elliptic curves from the finite quotient of the Fibonacci anyon character variety.

Curve	Conductor	Rank	$L'(E, 1)$
485b1	$485 = 5 \times 97$	1	1.72979
715b1	$715 = 5 \times 11 \times 13$	1	1.57871

5.5. The Finite Group $G = \mathbb{Z}_5 \rtimes 2O$, the Genetic Code and B-DNA

Our previous work [44] established that DNA codon organization follows the representation theory of the finite group $(240, 105) \cong \mathbb{Z}_5 \rtimes 20$ (here $20 \simeq 2O$). Conjugacy classes classify the 20 proteinogenic amino acids; degeneracy patterns (64 codons $\rightarrow$ 20 amino acids) reflect character-table symmetries. Irreducible characters aligned with amino-acid families correspond to MICs (minimal informationally complete POVMs) (Table 3 in [44]).

5.5.1. Emergence of Curve 300a1

From the character table, one extracts algebraic entries satisfying

$$C : y^2 = x^4 - x^3 - 4x^2 + 4x + 1, \quad (16)$$

with minimal model

$$E_{300a1} : y^2 = x^3 - x^2 - 13x + 22, \quad (17)$$

rank one, conductor $300 = 2^2 \cdot 3 \cdot 5^2$, and $L'(E_{300a1}, 1) \approx 1.384$.

5.5.2. Hydrodynamic DNA Correspondence

$L'(E_{300a1}, 1) \approx 1.384$ lies within the hydrodynamic B-DNA pitch/diameter range (1.30–1.50), as in Section 2 and Table 1. Hydrodynamic methods probe the effective cylinder including structured water and counter-ion sheaths, i.e., functional geometry rather than the ideal crystal.

5.6. The Finite Group $G = \mathbb{Z}_5 \rtimes 2T$ and Microtubule Structure

For $G = \mathbb{Z}_5 \rtimes 2T \cong (120, 15)$ we analyze its character table: 35 conjugacy classes (fifteen singlets, fifteen doublets, five triplets). As for the genetic code group, entries from nontrivial classes furnish MICs; here, our goal is the associated elliptic curves.

Two curves arise:

$$\text{Ell3} : y^2 = x^4 + x^3 + x^2 + x + 1, \quad (18)$$

$$\text{Ell4} : y^2 = x^4 + 2x^3 + 4x^2 + 8x + 16. \quad (19)$$

Minimal models:

$$E_{200b2} : y^2 = x^3 + x^2 - 3x - 2, \quad N = 200 = 2^3 \cdot 5^2, \quad L'(E, 1) \approx 1.088, \quad (20)$$

$$E_{880b2} : y^2 = x^3 + x^2 - 5x - 2, \quad N = 880 = 2^4 \cdot 5 \cdot 11, \quad L'(E, 1) \approx 1.869. \quad (21)$$

5.6.1. Microtubule Correspondence

$L'(E_{880b2}, 1) \approx 1.869$ lies in the experimental outer/inner diameter range (1.64–1.80); $L'(E_{200b2}, 1) \approx 1.088$ is near the 13-PF thinning ratio (1.10–1.30) (Section 2). This supports the view that these two curves capture a 13-protofilament MT geometry.

5.6.2. The Minimum Volume 3-Manifold $m003(-3, 1)$ as a Redundant Algebraic Pathway

Although indirect, one can *define* an elliptic curve from a 3-manifold's minimal polynomial [45]. Few small-discriminant hyperbolic manifolds yield genus-1 curves. Starting from $m003$ —the complement in S^3 of the figure-eight knot—the Dehn filling $M = m003(-3, 1)$ has a volume of ≈ 0.9427 (minimal among hyperbolic 3-manifolds). Its minimal polynomial is $m(x) = x^3 - x^2 + 1$, giving the elliptic curve $y^2 = m(x)$, already in minimal form: label 184a1 (conductor 184, discriminant -368 , bad primes $\{2, 23\}$) with $L'(E, 1) \approx 1.088$, coinciding with 200b2 and thus overdetermining the 13-PF thinning ratio.

A posteriori, $\pi_1(m003)$ is a Bianchi group [46]. Specifically, $\Gamma_k = \text{PSL}(2, \mathcal{O}_k) \subset \text{PSL}(2, \mathbb{C})$ acts on $\mathbb{H}_3$, with $\mathcal{O}_k$ the ring of integers of $\mathbb{Q}(\sqrt{-k})$. One has $m003 = \Gamma_{-3}(12)$ (index 12), defined over $\mathbb{Q}(\sqrt{-3})$, as for 485b1.

5.6.3. The Microtubule Substructure

A relevant substructural ratio is MT/actin diameter $\approx 25/7 \approx 3.5714$. The minimal form of Ell2 $\equiv 715b1$ is $y^2 + y = x^3 + x^2 - 5x + 6$. Removing y gives

$$y^2 = x^3 + x^2 - 5x + 6,$$

the minimal form of a rank-1 curve with conductor 16,176, discriminant $-16,176$, bad primes $\{2, 3, 337\}$, label 16176u1, and derivative $L'(E, 1) \approx 3.57025$, close to $25/7$ and consistent with 3.57 ± 0.51 .

5.6.4. Gross–Zagier Theory and Protofilament-Thinning Optimization

For 200b2 ($N = 2^3 \cdot 5^2$), Gross–Zagier requires $K = \mathbb{Q}(\sqrt{-D})$ respecting the Heegner hypothesis at the bad primes. Testing $D = 1$ gives $K = \mathbb{Q}(i)$: 2 ramifies, 5 splits, $h(-1) = 1$, $|U_K| = 4$, $D_K = -4$. Applying Gross–Zagier,

$$L'(E/\mathbb{Q}(i), 1) = \frac{8\pi^2\sqrt{4}}{16\Omega_E} \hat{h}(P_i) = \frac{\pi^2}{\Omega_E} \hat{h}(P_i). \quad (22)$$

Geometrically, $\mathbb{Z}[i]$ (Gaussian integers) provides a rectangular symmetry that is suited to PF packing and thinning; the 4th-root unit group captures 90° features that are relevant to lateral contacts. The coincidence $L'(E, 1) = 1.088$ for both 200b2 and 184a1 underscores a robust constraint arising by two independent routes (group hierarchy and hyperbolic 3-manifolds).

5.7. Summary: Optimal Quadratic Fields and Biological Complexity

We summarize the optimal imaginary quadratic fields (when they exist) for the curves in this section and their qualitative symmetries.

Simple conductors tend to admit clean class-number-1 fields ($\mathbb{Q}(\sqrt{-3})$, $\mathbb{Q}(i)$), matching basic crystalline/rectangular symmetries; more complex conductors correlate with a higher-order arithmetic structure, consistent with more sophisticated biological function.

5.8. Arithmetic Complexity and Biological Function (Compact)

This subsection summarizes how conductor structure correlates with the existence (or absence) of a clean imaginary quadratic field in the Gross–Zagier framework, and how this mirrors biological sophistication. We retain your original logic and examples while compressing repetition.

Simple conductors, clean fields.

Curves with **simple** conductors tend to admit optimal class-number-1 fields:

- 485b1 ($N = 5 \times 97$): both primes $\equiv 1 \pmod{4}$; optimal field $\mathbb{Q}(\sqrt{-3})$ (hexagonal symmetry). *Static information storage* (B-DNA crystalline geometry).
- 200b2 ($N = 2^3 \times 5^2$): two distinct primes only; $\mathbb{Q}(i)$ (rectangular symmetry). *Discrete assembly dynamics* (protofilament thinning).
- 880b2 ($N = 2^4 \times 5 \times 11$): three primes; $\mathbb{Q}(\sqrt{-19})$ as a more sophisticated clean field. *Transport/structure balance* (outer vs. inner channel).

Complex conductors, higher-order constraints.

Curves with **more intricate** conductors resist a simple quadratic field:

- 300a1 ($N = 2^2 \times 3 \times 5^2$): three distinct primes with mixed congruence classes and repeats; *no clean K*. *Genetic code organization* indicates higher-order structure.
- 715b1 ($N = 5 \times 11 \times 13$): three odd primes, mixed splitting; *no clean K*. *GDP-tubulin ring dynamics* suggests regulatory complexity.
- 16176u1 ($N = 2 \times 3 \times 337$): three distinct primes, mixed behavior; *no clean K*. *Actin/MT substructure* implies multi-constraint optimization.

Evolutionary optimization hierarchy.

1. Level 1—Simple geometry: clean quadratic fields $\Rightarrow$ basic crystalline/rectangular symmetries (DNA helix; core MT ratios).
2. Level 2—Moderate complexity: nontrivial clean fields (e.g., $\mathbb{Q}(\sqrt{-19})$) $\Rightarrow$ transport–structure trade-offs.
3. Level 3—Higher-order constraints: *no clean field* $\Rightarrow$ multi-route regulation (genetic code degeneracy; GDP rings; MT–actin interplay).

Predictive reading.

Absence of a simple K often predicts biological sophistication: for 300a1, genetic code robustness/error-correction; for 715b1, microtubule catastrophe regulation.

Beyond classical Gross–Zagier.

For cases without a clean K , optimization may operate through *higher* arithmetic structures.

Higher-Order Arithmetic Structures

When no single imaginary quadratic field satisfies the Heegner hypothesis cleanly, the observed biological sophistication suggests arithmetic mechanisms beyond the classical rank-1 Gross–Zagier setting. The following avenues provide a principled enlargement of the toolkit while staying within established arithmetic frameworks:

- *Beilinson–Bloch–Kato formulations* (higher algebraic K -theory): Extend the regulator paradigm to higher Chow groups/motivic cohomology, offering refined height pairings and special-value formulas well-suited to multi-constraint biological optimization [47].
- *Artin L -functions* for higher-degree extensions: Factorization of L -series via non-abelian representations captures composite splitting behavior across several primes, modeling layered regulation and assembly pathways [48].
- *Modular forms of higher levels*: Richer local data at multiple primes (old/new subspaces, Atkin–Lehner symmetries) encode a complex conductor structure and can reflect interacting biological modules [49].
- *Higher-dimensional varieties/nonabelian Hodge*: Character-variety components of dimension > 1 (and Simpson correspondences) represent families of local systems/rigidities beyond curves, aligning with multi-scale biological morphogenesis [50].

Arithmetic–geometric correspondences (summary).

Simple conductors $\longleftrightarrow$ classical Gross–Zagier $\longleftrightarrow$ basic biological geometry,

Complex conductors $\longleftrightarrow$ higher arithmetic structures $\longleftrightarrow$ advanced biological function.

Evolutionary mathematics and selection (concise).

Evolution alternates between (i) discovering simple, crystalline solutions reflected by a clean quadratic field K ; and (ii) developing complex, multi-route solutions captured by higher regulators, Artin factors, high-level modular data, or higher-dimensional character varieties. This positions arithmetic geometry as a predictive framework. The lack of a clean quadratic field is itself a mathematical signal of higher-order biological organization.

6. Discussion

The correspondence between elliptic curve L -function derivatives and fundamental biological structural ratios documented in this work represents more than a numerical coincidence—it points to deep organizational principles that may govern the architecture of life. Our analysis across the hierarchy $\mathbb{Z}_5 \times 2P$ suggests that biological optimization operates under arithmetic–geometric constraints of notable sophistication, while remaining an empirical program grounded in explicit curves, fields, and numerical invariants. We emphasize that our claims are quantitative and reproducible rather than metaphoric.

6.1. Implications for Evolutionary Theory

The precision of the correspondences—typically within 2–5% across multiple independent measurements—invites a reconsideration of how evolutionary optimization may operate. Traditional views treat biological structures as solutions to local fitness landscapes shaped by immediate selective pressures. Our results are consistent with a complementary perspective: evolution explores constraint spaces shaped by modular forms and elliptic curves, discovering configurations that satisfy the following simultaneously:

- Local geometric constraints (real periods Ω_E and Tamagawa numbers c_p);
- Global consistency (Tate–Shafarevich group $\text{Sha}(E)$);
- Information-theoretic optimization (canonical heights h_E);
- Discrete symmetry requirements (complex multiplication over suitable imaginary quadratic fields).

The association of different biological systems with distinct optimal fields— $\mathbb{Q}(\sqrt{-3})$ for hexagonal packing (B-DNA), $\mathbb{Q}(i)$ for rectangular motifs (microtubules), and $\mathbb{Q}(\sqrt{-19})$ for more intricate transport geometries—suggests a taxonomy of evolutionary constraints that mirrors the arithmetic of conductor factorization and field splitting. We do not claim a mechanism here; rather, we identify a stable numerical pattern whose falsifiable predictions are laid out in Section 5.8 and Table 5.

Table 5. Optimal imaginary quadratic fields for biological elliptic curves.

Curve	Biological System	$L'(E, 1)$	Conductor	Optimal Field	$h(-D)$	Symmetry
485b1	B-DNA crystalline	1.730	5×97	$\mathbb{Q}(\sqrt{-3})$	1	Hexagonal
715b1	pitch/Mgwidth	1.579	$5 \times 11 \times 13$	<i>none simple</i>	—	Higher-order
200b2	MT PF-thinning	1.088	$2^3 \times 5^2$	$\mathbb{Q}(i)$	1	Rectangular
880b2	MT outer/inner diam.	1.869	$2^4 \times 5 \times 11$	$\mathbb{Q}(\sqrt{-19})$	1	Complex
300a1	B-DNA hydrated	1.384	$2^2 \times 3 \times 5^2$	<i>none simple</i>	—	Higher-order
16176 u1	MT/actin diam.	3.570	$2 \times 3 \times 337$	<i>none simple</i>	—	Higher-order

6.2. Convergent Mathematical Pathways and Overdetermination

A striking feature is convergence from independent mathematical routes on the same biological ratios. The protofilament-thinning value $L'(E, 1) \approx 1.088$ arises both from group theory (200b2 from $\mathbb{Z}_5 \rtimes 2T$) and from hyperbolic geometry (184a1 via the manifold $m003(-3, 1)$). Such convergence increases robustness: distinct theoretical frameworks lead to the same quantitative target. Likewise, the MT/actin ratio $25/7 \approx 3.5714$ appears with $L'(E, 1) \approx 3.570$ for 16176u1, linking DNA arithmetic geometry and cytoskeletal architecture via explicit L -invariants. While causal interpretations remain open, the overdetermination is a strong indicator that the constraints we track are not accidental.

6.3. Quantum Information and Biological Computation

The emergence of our elliptic curves from Fibonacci anyon character varieties connects biological optimization to topological quantum computation [13,14]. Our claim does not require sustained macroscopic coherence. Rather, the discrete mathematical structures of quantum topology (fusion, braiding, modular data) act as organizational templates that are robust to noise. This viewpoint aligns with evidence for quantum effects in biology [51] while shifting emphasis from fragile coherence to symmetry and arithmetic structure as carriers of organizational information.

6.4. Implications for the Birch–Swinnerton-Dyer Conjecture

BSD relates $L'(E, 1)$ to heights, torsion, Tamagawa numbers, and $\text{Sha}(E)$. Our results suggest that, beyond its intrinsic mathematical importance, BSD captures a balance of scales and constraints that is useful for modeling complex organization. If biological structures repeatedly realize L -derivative values associated with simple conductors and class-number-1 fields, then biological data provide an unexpected testing ground for the structure, not the proof of BSD's predictions. We see this as a two-way bridge: arithmetic informs biology (predictive ratios), and biology motivates which arithmetic regimes (rank 1, simple fields) deserve focused computational scrutiny.

6.5. Fractal Scaling and the Golden-Ratio Context

The helical ratio $R = P/D$ fits within a broader scaling framework [4,52]. In our setting, the Fibonacci structure enters through quantum dimensions and fusion (powers of $\phi = (1 + \sqrt{5})/2$) [53]. Yet biological ratios (e.g., B-DNA $R \approx 1.70$) consistently exceed ϕ by 5–7%. This offset appears to be robust and interpretable. It reconciles idealized fractal scaling with molecular realities: base-pair geometry, hydration shells, and mechanical stability [54–56]. Thus the observed values look less like a quest for the pure golden ratio and more like the arithmetic–geometric optimum that is compatible with real biophysical constraints. This perspective goes beyond two-scale fractal models [57] by incorporating arithmetic data ($L'(E, 1)$, CM fields, conductors) as the “hidden parameters” steering feasible optima.

6.6. Limitations and Falsifiable Predictions

Scope. The present work makes no claim of a biochemical mechanism; it establishes quantitative correspondences and a reproducible arithmetic pipeline. **Data dependence.** Reported ratios rely on consensus measurements; tighter bounds could slightly shift target values. **Computational reproducibility.** All $L'(E, 1)$ values can be independently recomputed from the listed models and conductors (PARI/GP, SageMath, Magma). **Predictions.** (i) New systems with simple geometric ratios should be associated with rank-1 curves with simple conductors and class-number-1 fields; (ii) systems with complex, multi-scale regulation should correspond to curves lacking a clean Heegner field and instead exhibit

a higher-order arithmetic structure; (iii) measured shifts under environmental changes (hydration, ionic strength) should correlate with moving between curves within the same isogeny class or level. Potential falsifiers. A systematic survey finding no stable association between biological ratios and independently computed $L'(E, 1)$ values (within uncertainty) would refute the correspondence; likewise, failure to reproduce values from our explicit models would undermine the framework.

6.7. Future Directions and Broader Implications

This work opens several lines of inquiry.

6.7.1. Extended Biological Systems

Beyond B-DNA and microtubules, candidate testbeds include the following:

- Protein secondary-structure ratios (α -helices, β -sheets);
- Membrane organization (thickness/curvature);
- Ribosomal architecture (rRNA geometry);
- Chromatin compaction (nucleosome spacing, higher-order fibers).

6.7.2. Experimental Predictions

- Ratios near simple class-number-1 fields ($\mathbb{Q}(\sqrt{-3})$, $\mathbb{Q}(\sqrt{-19})$) should recur in systems with crystalline/rectangular symmetries.
- Systems tied to conductors with three or more distinct primes should show greater dispersion and context-dependence, consistent with a higher-order arithmetic structure (Section Higher-Order Arithmetic Structures).
- Quantitative correlations between conductor complexity and regulatory complexity (e.g., catastrophe control in MTs) are testable on curated datasets.

6.7.3. Computational Biology Applications

The arithmetic–geometric framework suggests new approaches:

- Protein structure prediction augmented by elliptic invariants;
- Drug design that targets symmetry-compatible binding geometries;
- Synthetic biology that engineers modules matching optimal arithmetic constraints.

These avenues remain speculative but are actionable: each reduces to computing $L'(E, 1)$ for candidate curves and testing fit to experimentally accessible ratios, exactly as demonstrated here.

7. Conclusions

We have demonstrated that fundamental biological structural ratios correspond with good precision to the L -function derivatives of elliptic curves emerging from the character varieties of finite quotients of Fibonacci anyon braid groups. This correspondence may be interpreted as biological optimization operating under arithmetic–geometric constraints encoded in elliptic curve L -functions, positioning the Birch–Swinnerton-Dyer conjecture and Gross–Zagier theory as frameworks that encode balance conditions between geometry, arithmetic, and information, principles that appear to be mirrored in cellular architecture.

The systematic hierarchy from quantum topology ($\mathbb{Z}_5 \rtimes 2P$ finite groups) through arithmetic geometry (elliptic curves and their L -functions) to biological structure (DNA and microtubule ratios) establishes a previously unexplored bridge between the deepest problems in pure mathematics and the fundamental architecture of life. The convergence of independent mathematical pathways on identical biological values, the predictive relationship between conductor complexity and biological sophistication, and the natural geometric interpretations provided by optimal imaginary quadratic fields collectively

suggest that evolutionary optimization operates within constraint spaces of remarkable arithmetic depth.

Our results further imply that biological evolution can be viewed as a vast computational process exploring the parameter spaces of arithmetic geometry, discovering viable configurations through constraints that mathematicians recognize as modular and number-theoretic. This positions arithmetic geometry not merely as abstract number theory, but as a mathematical blueprint underlying the helical geometries that are essential for life.

The correspondence unveiled here opens an entirely new frontier in mathematical biology: the most abstract achievements of pure mathematics (the theory of elliptic curves, the Birch–Swinnerton-Dyer conjecture, the Gross–Zagier formula, and topological quantum field theory) find natural application in understanding how life achieves its remarkable organizational sophistication through evolutionary optimization under arithmetic–geometric constraints. By bridging explicit number-theoretic invariants with measurable biological ratios, we move toward a quantitative and reproducible synthesis of geometry, topology, and biology. Future investigations along these lines promise to illuminate both the principles governing biological organization and the mathematical structures that evolution has discovered through billions of years of optimization within the constraint spaces of algebraic number theory.

As a final note, the present paper belongs to a broader series whose goal is to establish connections between $SU(2)_k$ anyons and the hierarchical layers of reality: physics and the geosphere ($k = 2$) [58], biology and the biosphere ($k = 3$), and neutrinos and the noosphere ($k = 4$) [59]. The celebrated trilogy *geosphere–biosphere–noosphere*, first articulated by Vladimir Vernadsky and Pierre Teilhard de Chardin [60], serves as a philosophical scaffold for this program, situating mathematical hierarchy within an evolutionary cosmology of consciousness. The forthcoming paper [61] will further develop this connection within the framework of $SU(2)_4$ and the noospheric domain.

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