Coherence Rings, Global Holonomies, and Recursive Stability

Toward a Coherence-Geometric Interpretation of Particle Masses, Gauge Structure, and Confinement

Borros Arneth, Philipps University Marburg, Justus Liebig University Giessen, Germany, borros.arneth@staff.uni-marburg.de

Abstract

We investigate a coherence-geometric framework in which particle masses, gauge structures, confinement phenomena, and recursive organization emerge from networks of triple-coherence rings connected through global coherence belts. The framework is motivated by an empirical particle-mass relation characterized by four integer exponents that appear across leptonic, hadronic, gauge-boson, and Higgs sectors. Rather than interpreting these exponents solely as interaction-specific quantities, we explore the possibility that they represent geometric invariants of an underlying coherence architecture. The theory begins from a complex coherence variable whose polar decomposition naturally generates phase symmetry. Extension to a three-component coherence state leads to triple-coherence rings possessing both local transport structure and global closure properties. The resulting geometry admits natural interpretations of U(1) and SU(3) symmetry, Wilson-loop-like holonomies, confinement, asymptotic freedom, and recursive feedback processes. A unified stability functional is proposed in which particle masses arise from discrete stable sectors of coherence geometry. The framework preserves familiar QCD interpretations within hadronic systems while embedding them into a broader coherence-geometric hierarchy. Although exploratory, the approach suggests a common geometric language linking particle spectra, internal symmetries, recursive dynamics, and global coherence organization.

1. Introduction

The origin of particle masses remains one of the most important open questions in modern theoretical physics. The Standard Model successfully describes electromagnetic, weak, and strong interactions through the gauge structure

$$SU(3)_C \times SU(2)_L \times U(1)_Y,$$

yet the numerical values of particle masses remain empirical parameters that must be inserted into the theory rather than derived from first principles [1],[2],[3],[4].

Historically, major advances in physics have frequently emerged through the discovery of deeper geometric structures. Einstein's formulation of general relativity reinterpreted gravitation as spacetime curvature [5]. Yang and Mills subsequently demonstrated that gauge interactions could be understood as geometric transport phenomena in internal symmetry spaces [6]. This geometric perspective was later expanded through fiber bundles, holonomies, topology, and differential geometry, which today form the mathematical language of modern gauge theory [7],[8],[9],[10].

At the same time, numerous attempts have sought to uncover deeper organizational principles beneath the observed particle spectrum. Composite models, preon theories, and rishon constructions have explored the possibility that quarks and leptons emerge from more fundamental building blocks obeying relatively simple combinatorial rules [11],[12],[13]. Quantum chromodynamics itself exhibits remarkable triple structures through color triplets, three-quark baryons, and non-Abelian gluonic self-interactions [14],[15],[16],[17].

The present work is motivated by the empirical mass relation

$$m = m_0\, 2^a\, 3^b\, (3\pi)^c \left(1-\frac{1}{3\pi}\right)^{-d/8} \qquad (1)$$

where a, b, c, and d are integer-valued parameters characterizing particle states.

A particularly intriguing feature of Eq. (1) is that the same exponent structure appears across a wide variety of sectors, including leptons, quarks, mesons, baryons, gauge bosons, and the Higgs boson. Such universality raises the possibility that the exponents reflect deeper organizational principles rather than sector-specific interaction counts.

Earlier interpretations associated the exponent b with effective quark-quark-gluon interaction structures and the exponent c with effective three-gluon interaction structures. These interpretations possess natural motivation within QCD. However, the appearance of the same exponents in non-hadronic systems suggests that a more universal explanation may exist.

In this article we explore the possibility that the exponents correspond to geometric invariants of an underlying coherence architecture. The conventional QCD interpretation is not discarded but is instead regarded as a specific realization of a more general coherence-geometric structure.

The framework is built upon two fundamental concepts:

1. Triple-coherence rings.
2. Global coherence belts.

Triple-coherence rings describe local coherence transport among three coupled coherence sectors. Coherence belts describe global closure, recursive feedback, and topological organization of the entire coherence network.

Together these structures provide a unified geometric language connecting particle masses, gauge symmetry, confinement, asymptotic freedom, recursive dynamics, and stability.

2. From Complex Coherence to Triple-Coherence Geometry

The starting point of the framework is the complex coherence variable

$$Z = M + iQ, \qquad (2)$$

where M and Q represent two orthogonal coherence sectors.

The polar decomposition

$$Z = Re^{i\Theta} \qquad (3)$$

immediately introduces a phase degree of freedom. The phase variable

$$\Theta \in [0,2\pi) \qquad (4)$$

defines a circular transport geometry supporting the transformation

$$Z \to e^{i\phi}Z. \qquad (5)$$

The resulting symmetry corresponds to the Abelian group

$$U(1). \qquad (6)$$

This structure is familiar from electromagnetism and quantum mechanics, where phase transport generates gauge symmetry [2],[6],[7].

However, many observed structures in particle physics exhibit a recurring triplicity. Examples include color triplets, baryonic three-quark organization, and the repeated appearance of powers of three within Eq. (1) [14],[15],[16],[17].

Motivated by these observations, we introduce the triple-coherence state

$$\Psi = \begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \end{pmatrix}. \qquad (7)$$

The fundamental coherence cycle becomes

$$Z_1 \to Z_2 \to Z_3 \to Z_1. \qquad (8)$$

We refer to this structure as a triple-coherence ring.

Unlike a single coherence orbit, the triple ring supports both collective and relative transport among its components. This additional internal structure leads naturally to non-Abelian coherence geometry.

3. State Space and Projective Geometry

The triple-coherence state may be regarded as an element of the complex vector space

$$\Psi \in \mathbb{C}^3. \qquad (9)$$

The physically relevant information resides in coherence relations rather than absolute normalization. We therefore impose

$$\Psi^\dagger \Psi = 1. \qquad (10)$$

Normalized states form the sphere

$$S^5 \subset \mathbb{C}^3. \qquad (11)$$

Because global phase transformations leave observable coherence relations unchanged,

$$\Psi \sim e^{i\phi}\Psi, \qquad (12)$$

physical states correspond to equivalence classes under phase identification.

The resulting configuration space is the complex projective manifold

$$\mathbb{CP}^2. \qquad (13)$$

Projective state spaces play a central role throughout quantum theory, geometric phases, and gauge structures [8],[9],[18],[19].

Within the present framework, $\mathbb{CP}^2$ provides the natural state space of triple-coherence rings.

Each coherence component may be written as

$$Z_i = R_i e^{i\theta_i}. \qquad (14)$$

The normalization condition becomes

$$R_1^2 + R_2^2 + R_3^2 = 1. \qquad (15)$$

The physically relevant quantities are the relative phases

$$\Delta_{12} = \theta_1 - \theta_2, \qquad (16)$$
$$\Delta_{23} = \theta_2 - \theta_3, \qquad (17)$$
$$\Delta_{31} = \theta_3 - \theta_1. \qquad (18)$$

Because the ring is closed,

$$\Delta_{12} + \Delta_{23} + \Delta_{31} = 0. \qquad (19)$$

Thus the coherence geometry is governed by a constrained set of internal phase relations rather than independent absolute phases.

4. Emergence of U(1) and SU(3)

The triple-coherence state supports two distinct classes of transformations.

The first consists of collective transport,

$$\Psi \rightarrow e^{i\phi}\Psi. \qquad (20)$$

All coherence sectors rotate simultaneously.

This symmetry corresponds to

$$U(1). \qquad (21)$$

The second class consists of internal coherence redistributions,

$$\Psi \to U\Psi, U \in SU(3), \qquad (22)$$

which preserve the coherence norm

$$\Psi^{\dagger}\Psi = 1. \qquad (23)$$

Combining both structures yields

$$U(3) \simeq SU(3) \times U(1). \qquad (24)$$

Within conventional gauge theory this relation is a standard group-theoretical result [16],[20].

Within the coherence framework it acquires a direct geometric interpretation.

The $U(1)$ sector describes collective transport of the entire coherence ring.

The $SU(3)$ sector describes relative transport among the three coherence components.

Consequently, non-Abelian structure emerges naturally from coherence-preserving deformations of the triple ring rather than being introduced as an external assumption.

The eight generators of $SU(3)$, represented by the Gell-Mann matrices, may then be interpreted as independent deformation modes of the coherence geometry [16],[20].

This interpretation provides the foundation for the gauge-theoretic structures developed in the following sections.

5. Local Coherence Transport and Gauge Connections

If the coherence state varies throughout spacetime,

$$\Psi = \Psi(x), \qquad (25)$$

local coherence transformations become

$$\Psi(x) \rightarrow U(x)\Psi(x). \qquad (26)$$

Ordinary derivatives do not transform covariantly under such local transformations. Consistency therefore requires the introduction of a compensating transport field,

$$D_\mu = \partial_\mu + A_\mu. \qquad (27)$$

The connection transforms according to

$$A_\mu \rightarrow U A_\mu U^{-1} - (\partial_\mu U)U^{-1}, \qquad (28)$$

which is precisely the transformation law of a Yang–Mills gauge field [6],[7],[8].

Within the coherence interpretation, the connection does not initially represent a physical force field. Rather, it represents a local coherence-transport structure required to compare neighboring coherence configurations consistently.

The corresponding curvature is

$$F_{\mu\nu} = [D_\mu, D_\nu], \qquad (29)$$

or explicitly,

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + [A_\mu, A_\nu]. \qquad (30)$$

The commutator term distinguishes non-Abelian transport from Abelian transport and generates the self-interacting structure characteristic of Yang–Mills theories [2],[6],[15].

Within the present framework, the curvature measures incompatibility between neighboring coherence transports and therefore quantifies local coherence frustration.

6. Triple-Coherence Rings and Coherence Belts

The triple-coherence ring describes local coherence organization.

However, local transport alone does not define a complete physical structure.

A second level of organization is required to enforce global coherence consistency.

To visualize this distinction, consider three coupled gears arranged in a closed triangular configuration.

Each gear represents one coherence component,

$$(Z_1, Z_2, Z_3).$$

Local contact points between neighboring gears represent local coherence-transfer processes.

The circulation

$$Z_1 \to Z_2 \to Z_3 \to Z_1 \qquad (31)$$

describes local transport around the ring.

The gears alone, however, do not guarantee global coherence.

For this reason we introduce a surrounding coherence belt.

The belt connects the entire structure and imposes the global closure condition

$$Z_1 \leftrightarrow Z_2 \leftrightarrow Z_3 \leftrightarrow Z_1. \qquad (32)$$

The distinction between gears and belts is fundamental.

The gears represent local coherence transfer.

The belt represents global coherence consistency.

This dual structure introduces a natural separation between local and global invariants.

7. Wilson Loops and Global Coherence Holonomy

The coherence belt admits a direct mathematical interpretation.

A complete traversal around the belt corresponds to a closed transport cycle.

In gauge theory such closed transport processes are characterized by Wilson loops [21],

$$W(C) = \mathrm{Tr}\,\mathcal{P}\mathrm{exp}\left(\oint_C A_\mu \, dx^\mu\right). \qquad (33)$$

The quantity $W(C)$ measures the accumulated transport associated with a complete closed cycle.

Within the coherence framework, the Wilson loop becomes a measure of global coherence closure.

The coherence belt therefore acquires the interpretation of a global holonomy structure.

This observation establishes a direct connection between coherence geometry and gauge-theoretic topology.

Local transport is described by the gauge connection.

Global coherence organization is described by Wilson-loop-like holonomies.

The coexistence of local and global structure becomes one of the central features of the framework.

8. Interpretation of the Exponent a

We now return to the empirical mass relation

$$m = m_0\, 2^a\, 3^b\, (3\pi)^c \left(1-\frac{1}{3\pi}\right)^{-d/8}. \qquad (34)$$

The factor

$$2^a \qquad (35)$$

is naturally associated with the binary structure already present in

$$Z = M + iQ. \qquad (36)$$

The coherence state therefore contains two fundamental sectors.

We define

$$a = N_M - N_Q, \qquad (37)$$

where N_M and N_Q represent effective occupation measures of the two coherence sectors.

The exponent a therefore characterizes binary coherence polarization.

Thus,

$$a = \text{binary coherence polarization.} \qquad (38)$$

This interpretation applies universally and does not depend on whether the physical realization corresponds to a lepton, quark, hadron, gauge boson, or Higgs state.

9. Interpretation of the Exponent b

The second contribution,

$$3^b \qquad (39)$$

was originally interpreted as an effective count of quark–quark–gluon interaction structures,

$$b \sim N_{qqg} \qquad (40)$$

Within hadronic systems this interpretation remains meaningful.

However, leptons and electroweak particles also exhibit nonzero values of b.

Consequently, the exponent cannot universally count literal QCD vertices.

Within the coherence-ring framework, local gear contacts provide a more general interpretation.

Each active contact corresponds to a local coherence-transfer process.

We therefore define

$$b = N_{\text{active contacts}}. \qquad (41)$$

Equivalently, the triple ring admits two orientations,

$$Z_1 \to Z_2 \to Z_3 \to Z_1, \qquad (42)$$

and

$$Z_1 \to Z_3 \to Z_2 \to Z_1. \qquad (43)$$

This motivates the introduction of a coherence winding invariant,

$$W = N_{\mathrm{cw}} - N_{\mathrm{ccw}}. \qquad (44)$$

The exponent may then be interpreted as

$$b = W. \qquad (45)$$

Thus,

$$b = \text{local coherence-transfer invariant.} \qquad (46)$$

The original QCD interpretation becomes

$$N_{\text{active contacts}} \to N_{qqg}. \qquad (47)$$

QCD therefore appears as a specific realization of a more general coherence-geometric quantity.

10. Interpretation of the Exponent c

The third factor,

$$(3\pi)^c, \qquad (48)$$

was originally associated with effective three-gluon interaction structures,

$$c \sim N_{ggg}. \qquad (49)$$

Again, this interpretation works naturally within hadronic systems but cannot universally explain nonzero values of c in leptonic sectors.

The coherence-belt picture suggests a broader interpretation.

A complete traversal of the belt defines a global coherence cycle.

We therefore define

$$c = N_{\mathrm{loops}}. \qquad (50)$$

The exponent counts independent global coherence loops supported by the network.

Consequently,

$$c = \text{global coherence-loop invariant.} \qquad (51)$$

The QCD interpretation then emerges as

$$N_{\text{loops}} \to N_{ggg}. \qquad (52)$$

Thus the original physical interpretation is preserved while acquiring a more universal geometric meaning.

11. The Geometric Origin of the Factor 3π

One of the most intriguing features of Eq. (34) is the appearance of the constant 3π.

Within the coherence-belt framework a simple geometric interpretation emerges.

Suppose each transition between neighboring coherence sectors contributes an effective phase inversion of magnitude

$$\pi.$$

A complete traversal of the triple ring then accumulates

$$\pi + \pi + \pi = 3\pi. \qquad (53)$$

We define

$$A_{\text{cycle}} = 3\pi \qquad (54)$$

as the fundamental action associated with a complete global coherence cycle.

The factor

$$(3\pi)^c$$

then represents the contribution of c independent coherence loops.

This interpretation links the numerical constant directly to the topology of the triple-coherence ring and its surrounding coherence belt.

12. Local and Global Hierarchies

The coherence framework suggests a natural hierarchy.

Local coherence transfer generates the invariant b.

Global coherence closure generates the invariant c.

In hadronic systems these become

$$b = N_{qqg}, \qquad (55)$$

and

$$c = N_{ggg}. \qquad (56)$$

Thus the familiar hierarchy of QCD interaction structures emerges naturally.

Local quark-gluon exchange corresponds to local coherence transfer.

Gluonic self-interaction corresponds to global coherence organization.

The coherence interpretation therefore does not replace QCD but provides a geometric layer beneath it.

In this picture, hadronic QCD structures become observable manifestations of deeper coherence-geometric invariants.

13. Recursive Feedback and the Exponent d

The final contribution to the mass relation is

$$\left(1 - \frac{1}{3\pi}\right)^{-d/8}. \qquad (57)$$

Among all factors appearing in Eq. (34), this term is the most unusual. Unlike the powers of two, three, and 3π, it possesses the structure of a resummed geometric series.

Within the coherence-belt framework, a natural interpretation emerges.

Suppose a coherence cycle completes one traversal of the global coherence belt. Because the coherence network is closed, a fraction of the transported coherence may return and circulate again. Repeated traversals generate the series

$$1+\frac{1}{3\pi}+\frac{1}{(3\pi)^2}+\frac{1}{(3\pi)^3}+\cdots. \tag{58}$$

The infinite sum is

$$\sum_{n=0}^{\infty}\left(\frac{1}{3\pi}\right)^n=\left(1-\frac{1}{3\pi}\right)^{-1}. \tag{59}$$

The recursive factor in the mass formula therefore acquires an immediate interpretation as the accumulated contribution of repeated coherence traversals.

We define

$$d=N_{\text{feedback}}, \tag{60}$$

where N_{feedback} counts independent recursive coherence-feedback channels.

The exponent therefore becomes

$$d=\text{recursive coherence-feedback invariant.} \tag{61}$$

The four exponents may now be summarized as

$$a=\text{binary coherence polarization,} \tag{62}$$
$$b=\text{local coherence-transfer invariant,} \tag{63}$$
$$c=\text{global coherence-loop invariant,} \tag{64}$$
$$d=\text{recursive coherence-feedback invariant.} \tag{65}$$

Together they describe complementary aspects of coherence organization.

14. The Appearance of Eight

The recursive contribution contains the factor

$$\frac{d}{8}. \tag{66}$$

An intriguing observation is

$$\dim(SU(3)) = 8. \qquad (67)$$

Since the triple-coherence ring naturally generates an $SU(3)$ transport structure, one may speculate that recursive coherence feedback is distributed among the eight independent deformation modes of the coherence geometry.

In this interpretation, the factor eight reflects the dimensionality of the internal transport manifold.

Although this connection remains speculative, it provides a possible geometric explanation for a numerical feature of the empirical mass relation that otherwise appears mysterious.

15. Effective Coherence Action

The four contributions may be combined into a single effective coherence functional.

The binary contribution is

$$S_a = a \ln 2, \qquad (68)$$

the local-transfer contribution is

$$S_b = b \ln 3, \qquad (69)$$

the global-loop contribution is

$$S_c = c \ln(3\pi), \qquad (70)$$

and the recursive contribution is

$$S_d = -\frac{d}{8} \ln\left(1 - \frac{1}{3\pi}\right). \qquad (71)$$

Combining these terms yields

$$S_{\text{eff}} = a\ln\ 2 + b\ln\ 3 + c\ln\,(3\pi) - \frac{d}{8}\ln\,\left(1 - \frac{1}{3\pi}\right). \qquad (72)$$

Exponentiation immediately reproduces the empirical mass relation,

$$m = m_0 e^{S_{\text{eff}}}. \qquad (73)$$

This expression suggests that particle masses may be interpreted as measures of coherence organization.

Rather than treating mass as a fundamental property, the framework views mass as an emergent quantity associated with the stability and complexity of coherence structures.

16. Stability Hypothesis

The central conjecture of the framework may now be stated explicitly.

Stability Hypothesis

Physical particles correspond to stable extrema of an underlying coherence functional

$$S[\Psi]. \qquad (74)$$

The observed exponent values are not fundamental inputs but invariants associated with stable coherence sectors.

The stability condition becomes

$$\delta S[\Psi] = 0. \qquad (75)$$

Stable solutions may then be classified according to the integer quadruples

$$(a, b, c, d). \qquad (76)$$

The observed particle spectrum would emerge from a discrete set of admissible coherence configurations.

This interpretation naturally explains why integer-valued exponents appear throughout the spectrum.

Integers frequently arise whenever stability is governed by topology, winding numbers, holonomies, or quantized transport structures [9],[18-20].

17. Confinement as Global Belt Stability

The coherence-belt picture provides a simple geometric interpretation of confinement.

The components of a triple-coherence ring are not independent entities.

They are connected by the global coherence belt.

Removing one component requires deformation of the entire coherence structure.

The associated energy therefore grows with increasing separation.

This behavior resembles the confining potential observed in quantum chromodynamics [21],[22].

Symbolically,

$$E_{\mathrm{belt}} \propto L, \qquad (77)$$

where L denotes the deformation length of the coherence belt.

This is analogous to the linear confinement potential

$$V(r) \approx \sigma r \qquad (78)$$

The coherence framework therefore suggests the interpretation

$$\text{Confinement} = \text{global coherence-belt stability}. \qquad (79)$$

Importantly, this is not a derivation of QCD confinement. Rather, it provides a geometric interpretation of why confinement-like behavior may emerge naturally in globally closed coherence structures.

18. Asymptotic Freedom

The same geometry suggests an interpretation of asymptotic freedom.

At short distances only neighboring coherence sectors interact significantly.

The global coherence belt remains essentially undeformed.

Local coherence-transfer processes therefore dominate.

The effective interaction becomes weak.

At larger distances the global coherence belt becomes increasingly important. Recursive feedback and global coherence organization contribute more strongly, increasing the effective interaction strength.

This behavior qualitatively resembles the asymptotic freedom discovered in non-Abelian gauge theories [15],[17].

Within the coherence framework,

$$\text{Asymptotic Freedom} = \text{dominance of local coherence transport over global coherence closure.} \quad (8$$

Again, this interpretation is qualitative rather than quantitative, but it establishes a geometric analogy between coherence transport and gauge-theoretic dynamics.

19. Recursive Hierarchies

One of the most striking features of the framework is its recursive character.

The same geometric structure may appear repeatedly at different organizational levels,

$$(M, Q) \to \text{coherence modes} \to \text{preonic structures} \to \text{quarks} \to \text{baryons.} \quad (81)$$

The physical realization changes.

The underlying geometry remains similar.

This recursive viewpoint provides a possible explanation for the repeated appearance of triple structures throughout particle physics.

Whether such recursive organization represents a genuine microscopic feature of nature remains an open question, but it offers an appealing conceptual framework linking otherwise disparate sectors of the particle spectrum.

20. Discussion

The coherence-ring and coherence-belt framework proposed here should be regarded as exploratory.

Its purpose is not to replace the Standard Model, quantum chromodynamics, or established gauge theory.

Instead, the framework seeks to provide a geometric interpretation of an empirical exponent structure that appears across multiple particle sectors.

A central result is the emergence of a hierarchy connecting local and global coherence organization.

Local coherence transport generates the invariant b.

Global coherence closure generates the invariant c.

Recursive coherence return generates the invariant d.

Within hadronic systems these quantities naturally reduce to familiar QCD structures,

$$b \to N_{qqg}, \qquad (82)$$
$$c \to N_{ggg}. \qquad (83)$$

The framework therefore preserves the original hadronic interpretation while embedding it into a broader coherence-geometric picture.

Several important challenges remain.

First, the empirical mass relation itself still lacks derivation from a microscopic theory.

Second, the correspondence between coherence invariants and QCD interaction structures has not yet been established rigorously.

Third, quantitative derivations of confinement, asymptotic freedom, and particle masses remain to be developed.

Future work should focus on constructing an explicit coherence action whose stable solutions reproduce the observed exponent values without phenomenological input.

21. Conclusions

We have developed a coherence-geometric framework based on triple-coherence rings and global coherence belts.

The framework provides a unified interpretation of the exponent structure

$$(a, b, c, d)$$

appearing in the empirical particle-mass relation

$$m = m_0\, 2^a\, 3^b\, (3\pi)^c \left(1 - \frac{1}{3\pi}\right)^{-d/8}$$

Within the proposed interpretation,

$a =$ binary coherence polarization,
$b =$ local coherence-transfer invariant,
$c =$ global coherence-loop invariant,
$d =$ recursive coherence-feedback invariant.

The framework naturally connects:

- phase symmetry,
- projective geometry,
- $SU(3)$ transport structure,
- Wilson-loop-like holonomies,
- confinement,
- asymptotic freedom,
- recursive feedback,
- and particle-mass organization

within a common geometric language.

The original hadronic interpretations,

$$b = N_{qqg}, c = N_{ggg},$$

remain valid as specific realizations of more general coherence invariants.

Whether the coherence geometry represents a fundamental layer of physical reality remains an open question. Nevertheless, the framework suggests that many apparently unrelated structures of particle physics may be different manifestations of a common underlying coherence architecture.

A decisive test of the theory will require the construction of a microscopic coherence dynamics whose stable solutions reproduce the observed particle spectrum and generate the exponent values from first principles.

Declarations

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The author declares no competing interests.

Author Contributions

B.A. conceived the framework, developed the theoretical formalism, performed the analysis, and wrote the manuscript.

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Code Availability

No software was used.

Ethics Approval

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Consent to Participate

Not applicable.

Consent for Publication

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References

[1] Weinberg S. *The Quantum Theory of Fields. Vol. 1: Foundations*. Cambridge University Press; 1995.

[2] Peskin ME, Schroeder DV. *An Introduction to Quantum Field Theory*. Addison-Wesley; 1995.

[3] Schwartz MD. *Quantum Field Theory and the Standard Model*. Cambridge University Press; 2014.

[4] Griffiths D. *Introduction to Elementary Particles*. 2nd ed. Wiley-VCH; 2008.

[5] Einstein A. Die Grundlage der allgemeinen Relativitätstheorie. *Ann Phys*. 1916;49:769–822.

[6] Yang CN, Mills RL. Conservation of isotopic spin and isotopic gauge invariance. *Phys Rev*. 1954;96:191–195.

[7] Wu TY, Yang CN. Concept of nonintegrable phase factors and global formulation of gauge fields. *Phys Rev D*. 1975;12:3845–3857.

[8] Frankel T. *The Geometry of Physics*. 3rd ed. Cambridge University Press; 2011.

[9] Nakahara M. *Geometry, Topology and Physics*. 2nd ed. Taylor & Francis; 2003.

[10] Connes A. *Noncommutative Geometry*. Academic Press; 1994.

[11] Harari H. A schematic model of quarks and leptons. *Phys Lett B*. 1979;86:83–86.

[12] Shupe MA. A composite model of leptons and quarks. *Phys Lett B*. 1979;86:87–92.

[13] Pati JC, Salam A. Lepton number as the fourth color. *Phys Rev D*. 1974;10:275–289.

[14] Gell-Mann M. A schematic model of baryons and mesons. *Phys Lett*. 1964;8:214–215.

[15] Fritzsch H, Gell-Mann M, Leutwyler H. Advantages of the color octet gluon picture. *Phys Lett B*. 1973;47:365–368.

[16] Georgi H. *Lie Algebras in Particle Physics*. 2nd ed. Westview Press; 1999.

[17] Gross DJ, Wilczek F. Ultraviolet behavior of non-Abelian gauge theories. *Phys Rev Lett*. 1973;30:1343–1346.

[18] Berry MV. Quantal phase factors accompanying adiabatic changes. *Proc R Soc Lond A*. 1984;392:45–57.

[19] Atiyah MF. *The Geometry and Physics of Knots*. Cambridge University Press; 1990.

[20] Penrose R. *The Road to Reality*. Jonathan Cape; 2004.

[21] Wilson KG. Confinement of quarks. *Phys Rev D*. 1974;10:2445–2459.

[22] Greensite J. *An Introduction to the Confinement Problem*. Springer; 2011

Figures

Figure 1. Triple-Coherence Ring and Coherence Belt (Gear–Belt Model)

Local Transport, Global Closure, and Recursive Feedback

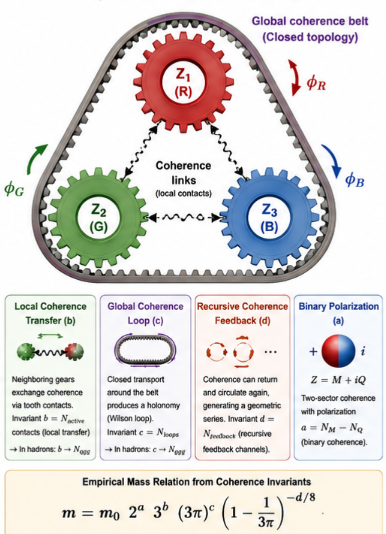

Figure 1 legend: Three coherence modes Z_1 (R), Z_2 (G), and Z_3 (B) are represented by interlocking gears enclosed by a closed tooth-belt. The gear teeth correspond to local coherence-transfer processes, whose count defines invariant b. The closed belt represents global coherence closure; a complete circulation around the belt yields the global-loop invariant c. Coherence traveling around the belt can return and circulate repeatedly, producing recursive feedback quantified by invariant d. The underlying binary coherence variable $Z = M + iQ$ gives the polarization invariant a. Together, (a, b, c, d) determine the particle mass through the empirical relation shown.

Figure 2. Gauge Transport, Holonomy, and SU(3) Structure

From Local Connections to Global Wilson Loops

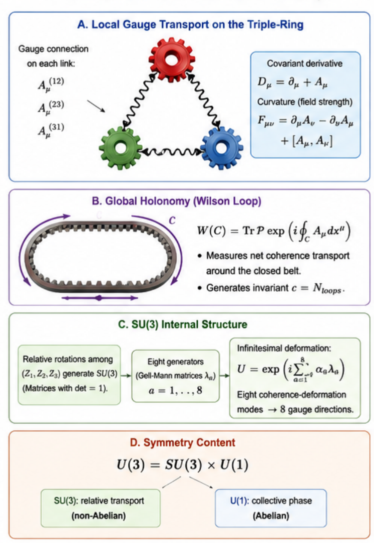

Figure 2 legend: Local coherence transport along the ring is described by gauge connections A_μ on each link. Their curvature $F_{\mu\nu}$ encodes local transport frustration and leads to Yang–Mills dynamics. The closed coherence belt defines a global Wilson loop $W(C)$, whose value yields the global-loop invariant c. Relative rotations among the three coherence modes generate the $SU(3)$ group, with eight generators corresponding to eight coherence-deformation modes (and eight gauge-field directions). Together with the collective $U(1)$ phase symmetry, the full symmetry structure is $U(3) = SU(3) \times U(1)$.

Figure 3. Confinement, Asymptotic Freedom, and Scale Dependence (Gear–Belt Picture)

From Short-Distance Dominance to Long-Distance Globality

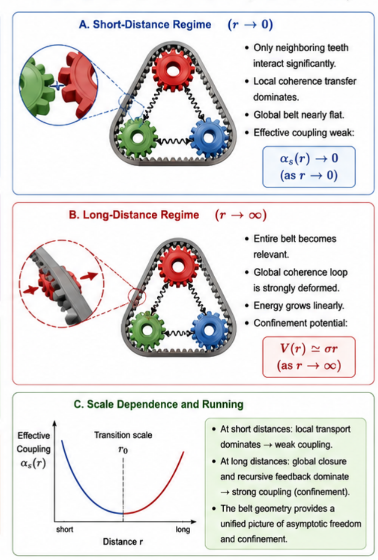

Figure 3 legend: The gear–belt system illustrates scale-dependent behavior. At short distances $(r \to 0)$, only neighboring teeth interact; local coherence transfer (i.e., invariant b) dominates and the effective coupling $\alpha_s(r)$ becomes small (asymptotic freedom). At large distances $(r \to \infty)$, the entire belt is stretched; global coherence loop (invariant c) and recursive feedback (invariant d) dominate, leading to a linearly rising potential $V(r) \simeq \sigma r$ (confinement). The bottom plot qualitatively shows the running coupling: decreasing at short distances and increasing at long distances, with a transition scale r_0 separating the regimes.

Figure Legends

Figure 1. Triple-Coherence Ring and Global Coherence Belt (Gear–Belt Model)

Three coherence modes Z_1, Z_2, and Z_3 are represented by interlocking gears enclosed by a closed tooth-belt. The gear teeth symbolize local coherence-transfer processes between neighboring coherence sectors. The number of active local contacts defines the local coherence-transfer invariant b. The surrounding coherence belt represents global coherence closure and supports complete circulations around the entire structure. Such closed traversals generate a global coherence-loop invariant c, analogous to a Wilson-loop holonomy in gauge theory. Repeated circulations around the belt produce recursive coherence feedback quantified by the invariant d. The underlying binary coherence variable $Z = M + iQ$ generates the polarization invariant a, representing the balance between two fundamental coherence sectors. Together, the four invariants (a, b, c, d) determine the empirical particle-mass relation

$$m = m_0\, 2^a\, 3^b\, (3\pi)^c \left(1 - \frac{1}{3\pi}\right)^{-d/8}.$$

The figure illustrates the central hypothesis of the coherence-geometric framework: particle properties emerge from the interplay of local coherence transport, global coherence closure, recursive feedback, and binary coherence polarization.

Figure 2. Gauge Transport, Holonomy, and SU(3) Structure in the Gear–Belt Model

The figure illustrates how gauge-theoretic structures emerge naturally from the triple-coherence geometry. **Panel A** shows local coherence transport along the triple ring. Neighboring coherence sectors are connected through local transport links described by gauge connections A_μ, while the associated curvature $F_{\mu\nu}$ characterizes local transport frustration and generates Yang–Mills-like dynamics. **Panel B** depicts the coherence belt as a closed transport path C, whose accumulated transport is described by the Wilson loop

$$W(C) = \mathrm{Tr}\,\mathcal{P}\exp\left(i \oint_C A_\mu\, dx^\mu\right).$$

The resulting holonomy defines the global coherence-loop invariant c. **Panel C** illustrates the internal symmetry structure of the triple-coherence state

$$\Psi = (Z_1, Z_2, Z_3)^T,$$

whose relative coherence rotations generate the non-Abelian group $SU(3)$. The eight generators correspond to eight independent coherence-deformation modes. **Panel D** summarizes the symmetry content of the framework. Collective phase transport generates the Abelian $U(1)$ symmetry, while relative coherence transport generates the non-Abelian $SU(3)$ structure. Together these produce the full symmetry group

$$U(3) \simeq SU(3) \times U(1).$$

The figure provides a geometric interpretation of gauge connections, holonomies, and non-Abelian symmetry in terms of local and global coherence transport.

Figure 3. Confinement, Asymptotic Freedom, and Scale Dependence in the Gear–Belt Model

The gear–belt representation provides a qualitative coherence-geometric interpretation of scale-dependent interaction behavior. **Panel A** illustrates the short-distance regime ($r \to 0$), where only neighboring gear teeth interact significantly. Local coherence-transfer processes dominate the dynamics, corresponding to the invariant b. The global coherence belt remains only weakly deformed, and the effective interaction strength becomes small, qualitatively resembling asymptotic freedom in non-Abelian gauge theories. **Panel B** shows the long-distance regime ($r \to \infty$), where deformation of the entire coherence belt becomes important. Global coherence-loop organization (c) and recursive coherence feedback (d) dominate the dynamics. Separation of the coherence components requires deformation of the complete belt structure, leading to confinement-like behavior qualitatively analogous to a linearly rising potential

$$V(r) \approx \sigma r.$$

Panel C presents the qualitative running of the effective coupling and identifies a transition scale r_0 separating local coherence-dominated and global coherence-dominated regimes.