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Article

A Dissipative Quantum Field Model of Whole-Organism Coherence: A Multi-Field Framework for Biological Integration Across Scales

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Abstract

Biological systems maintain coherent organization across spatial and temporal scales that cannot be fully explained by classical biochemical or electrophysiological models. Building on the dissipative quantum field theoretical framework introduced by Vitiello and collaborators, this work develops an organism-wide model in which coherence emerges from multiple quantum substrates undergoing spontaneous symmetry breaking (SSB). Each substrate—coherent water domains, microtubular dipole fields, mitochondrial excitons, chromatin vibrational dipoles, ionic phase waves, and large-scale electromagnetic modes—defines a distinct coherent sector represented by macroscopic fields Θ_1 – Θ_{12} . These fields are characterized by condensation amplitudes $\theta_k(t)$ derived from the vacuum structure. Using operator doubling, Bogoliubov transformations, and projection of the doubled Liouville equation, we obtain macroscopic evolution equations for $\theta_k(t)$ and show that their dynamics form a gradient flow on a multi-field free-energy landscape with a global attractor Θ_{ref} . The Biological Coherence Index (BCI), based on vacuum overlap, provides an experimentally accessible measure of whole-organism coherence. This framework offers a unified quantitative approach to long-range biological coherence, cross-scale coupling, and integrative regulation in living systems.

Keywords: dissipative quantum field theory; spontaneous symmetry breaking; biological coherence; Nambu–Goldstone modes; dipole-wave quanta; vacuum condensation; multi-scale physiology; quantum biology; electromagnetic coherence; systems biophysics; free-energy landscapes; integrative physiology

1. Introduction

Biological systems maintain coherent organization across spatial and temporal scales ranging from nanometers to the scale of the whole organism. Mitochondrial electron and proton transport exhibit signatures of excitonic and collective behavior (Nicholls & Ferguson, 2013; Wallace, 2010), intracellular water forms dipolar ordering domains (Del Giudice, Doglia, Milani & Vitiello, 1985; Pollack, 2013), microtubules support dipole oscillations and collective vibrational modes (Jibu & Yasue, 1995; Hameroff & Penrose, 2014), and large-scale neural and physiological oscillations show long-range phase coherence (Singer, 1999; Freeman, 2000; Goldberger et al., 2002). These phenomena are difficult to reconcile with classical biochemical or electrophysiological frameworks, which rely on local interactions, diffusion, and short-range signaling.

A deeper theoretical issue emerges: How do living systems preserve extended, robust coherence under permanently dissipative conditions? Traditional models of biochemical regulation do not explain long-range correlations, abrupt transitions between coherent states, or the integration of cellular, physiological, cognitive, and emotional processes into unified organismic dynamics.

Dissipative quantum field theory (DQFT), developed by Celeghini, Rasetti, and Vitiello (1992), offers a mathematically rigorous Framework for addressing such questions. DQFT extends standard quantum field theory by doubling degrees of freedom to represent environmental coupling (Umezawa, 1993; Breuer & Petruccione, 2002), introducing Bogoliubov transformations that generate

coherent excitations with condensation amplitudes θ_k (Celeghini, Rasetti & Vitiello, 1992), and yielding unitarily inequivalent vacuum states associated with distinct macroscopic orderings (Vitiello, 1995). These vacua arise through spontaneous symmetry breaking (SSB), generating long-range Nambu–Goldstone modes—dipole-wave quanta (DWQ)—that mediate coherence across scales (Del Giudice et al., 1988; Fröhlich, 1968). Free-energy minimization (Takahashi & Umezawa, 1975) selects dynamically preferred vacua, establishing attractor-like physiological configurations (Blasone, Jizba & Vitiello, 2011).

Although DQFT has been successfully applied to water coherence (Del Giudice et al., 1985), microtubular dynamics (Jibu & Yasue, 1995; Tuszynski, Hameroff & Sataric, 1995), and neural memory models (Ricciardi & Umezawa, 1967; Vitiello, 2001), existing work has focused on individual substrates rather than the organism as an integrated whole. However, physiology comprises multiple interacting domains—metabolic, immune, neural, interoceptive, structural, and electromagnetic—each associated with specific quantum substrates and coherence mechanisms.

The present work proposes a twelve-field coherence architecture representing distinct but coupled sectors of organismic order. Each coherence field Θ_k corresponds to a specific biological substrate undergoing symmetry breaking, with its own condensation amplitude $\theta_k(t)$. These fields include foundational intracellular coherence (Θ_1), immune and inflammatory regulation (Θ_2), autonomic balance (Θ_3), interoceptive integration (Θ_4), circulatory and motility coherence (Θ_5), mitochondrial metabolism (Θ_6), regenerative processes (Θ_7), chromatin and morphogenetic structure (Θ_8), circadian and restorative regulation (Θ_9), cognitive integration (Θ_{10}), affective dynamics (Θ_{11}), and whole-organism electromagnetic coherence (Θ_{12}).

By embedding this multi-field architecture into the dissipative QFT formalism, we derive macroscopic equations governing the temporal evolution of $\theta_k(t)$, show how these fields collectively define a global free-energy attractor Θ_{ref} , and introduce an experimentally accessible Biological Coherence Index (BCI) derived from vacuum overlap expressions.

The goal of this article is not to claim that biological systems require quantum explanations, but to show that the mathematical framework of DQFT provides a consistent way to model multi-scale coherence, state transitions, **and** integrative physiological dynamics. The resulting model offers testable predictions regarding cross-scale coupling, coherence breakdown, and susceptibility to external perturbations, making it relevant for systems biology, biophysics, and integrative physiology.

2. Methods: Dissipative Quantum Field Framework

This section develops the mathematical structure used to model biological coherence across multiple scales. The formalism is based on dissipative quantum field theory (DQFT), which provides a consistent treatment of open-system dynamics, spontaneous symmetry breaking (SSB), and long-range correlations in macroscopic systems (Umezawa, 1993; Celeghini, Rasetti & Vitiello, 1992; Breuer & Petruccione, 2002).

2.1. Operator Doubling and the Open-System Hilbert Space

A defining feature of DQFT is the doubling of degrees of freedom. For every quantum mode relevant to a biological substrate, two operator sets are introduced:

- physical operators: $\hat{a}_k, \hat{a}_k^\dagger$
- environmental (dissipative) operators: $\tilde{a}_k, \tilde{a}_k^\dagger$

which satisfy

$$[\hat{a}_k, \hat{a}_j^\dagger] = \delta_{kj},$$

$$[\tilde{a}_k, \tilde{a}_j^\dagger] = \delta_{kj},$$

all mixed commutators vanish.

The system's Hilbert space becomes a tensor product

$$H_{total} = H \otimes H,$$

where H carries biological excitations (water dipoles, microtubule dipole modes, chromatin excitons, ionic waves) and H' encodes environmental fluctuations such as hydration noise, ionic turbulence, or thermal damping (Del Giudice et al., 1985; Jibu & Yasue, 1995; Weiss, 2012).

This doubling is not optional—it is mathematically required to represent irreversible, dissipative dynamics at the operator level (Takahashi & Umezawa, 1975).

2.2. Bogoliubov Transformations and Condensation Amplitudes

Open-system evolution induces mixing between the physical and dissipative operators through Bogoliubov transformations:

$$A_k(\theta_k) = \hat{a}_k \cdot \cosh(\theta_k) - \tilde{a}_k^\dagger \cdot \sinh(\theta_k)$$
$$\tilde{A}_k(\theta_k) = \tilde{a}_k \cdot \cosh(\theta_k) - \hat{a}_k^\dagger \cdot \sinh(\theta_k)$$

The real parameter θ_k is the condensation amplitude associated with mode k .

Its condensate density

$$N_k = \sinh^2(\theta_k)$$

measures the degree of coherent ordering present even in the vacuum state. In biological systems, such condensation may correspond to water-domain coherence (Del Giudice et al., 1985; Pollack, 2013), microtubule dipole alignment (Jibu & Yasue, 1995; Hameroff & Penrose, 2014), chromatin excitonic ordering (Montagnier et al., 2011), or mitochondrial excitons (Nicholls & Ferguson, 2013).

2.3. Coherent Vacua and Unitary Inequivalence

The Bogoliubov-transformed operators define a family of coherent vacuum states:

$$|0(\theta)\rangle = \Pi_k [1 / \cosh(\theta_k)] \cdot \exp(\tanh(\theta_k) \cdot \hat{a}_k^\dagger \tilde{a}_k^\dagger) |0\rangle.$$

Different condensation patterns $\theta \neq \theta'$ yield unitarily inequivalent vacua, satisfying

$$\langle 0(\theta) | 0(\theta') \rangle = 0 \text{ (in the infinite-mode limit),}$$

which means the organism is not described by a single ground state but by a manifold of possible macroscopic coherence states (Vitiello, 1995; Blasone et al., 2011).

State transitions correspond to vacuum transitions, a mechanism proposed for memory switching, attention shifts, and large-scale physiological reconfiguration.

2.4. Spontaneous Symmetry Breaking and Dipole-Wave Quanta

Coherent biological substrates possess internal continuous symmetries—rotational dipole symmetry of water, orientational symmetry of microtubule dipoles, phase symmetry of protein vibrations, helical symmetry of chromatin dipoles, or U(1)-like ionic phase symmetries (Fröhlich, 1968; Del Giudice et al., 1985; Bizzarri et al., 2013).

Instability of such symmetries leads to spontaneous symmetry breaking (SSB), causing the system to settle in one of many possible coherence vacua. SSB generates Nambu–Goldstone (NG) excitations, which in dipolar biological materials appear as dipole-wave quanta (DWQ)—massless or near-massless collective oscillation modes with long correlation lengths (Del Giudice et al., 1988; Jibu & Yasue, 1995).

DWQ provide the physical mechanism for:

- intracellular water coherence,
- cytoskeletal synchronization,
- microtubular dipole alignment,
- tissue-scale ionic wave propagation,
- organism-wide EM coherence (Vitiello, 2014; Scholkmann, Fels & Cifra, 2013).

A minimal field-theoretic derivation of SSB and DWQ is provided in Appendix C.

2.5. Projection from the Doubled Liouville Equation

The microscopic state $q(t)$ evolves according to the doubled Liouville–von Neumann equation:
 $dq/dt = -i [H_{\text{total}}, q].$

To extract macroscopic dynamics, we define order-parameter observables O_k whose expectation values are

$$\theta_k(t) = \text{Tr} [\varrho(t) \cdot O_k].$$

Applying the Mori-Zwanzig projection operator formalism (Breuer & Petruccione, 2002), projecting $\varrho(t)$ onto the manifold of coherent vacua $|0(\theta(t))\rangle$, and assuming time-scale separation between slow order-parameter evolution and fast microscopic fluctuations, yields effective macroscopic evolution equations of the form:

$$d\theta_k/dt = A_k(\theta) + \text{noise}.$$

In the DQFT framework, the drift term $A_k(\theta)$ is shown to correspond to the gradient of the free-energy functional. A detailed derivation is provided in Appendix A.

2.6. Free-Energy Functional and Vacuum Selection

The free energy associated with the vacuum $|0(\Theta)\rangle$, where $\Theta = \{\theta_1, \dots, \theta_{12}\}$, is defined as

$$\mathcal{F}(\Theta) = \langle 0(\Theta) | H_{\text{total}} - (1/\beta) S | 0(\Theta) \rangle.$$

The physically realized coherence configuration satisfies

$$\partial \mathcal{F} / \partial \theta_k = 0$$

for all k (Takahashi & Umezawa, 1975; Vitiello, 1995).

Thus, the organism continuously relaxes toward the free-energy minimizing configuration Θ_{ref} , while interactions between fields distort this trajectory and allow multi-stability, bifurcations, and transitions between physiological states.

3. Results: Multi-Field Coherence Architecture and Dynamical Model

The dissipative quantum field framework developed in Section 2 allows biological coherence to be represented through a set of macroscopic order parameters $\theta_k(t)$, each associated with a coherent vacuum sector of a specific quantum substrate. In this section, we introduce a structured twelve-field architecture, derive the macroscopic dynamical equations governing these fields, and present the Biological Coherence Index (BCI) as an experimentally accessible measure.

3.1. Coherence Sectors Derived from Biological Quantum Substrates

The organism contains multiple quantum substrates capable of spontaneous symmetry breaking (SSB), including coherent water domains (Del Giudice et al., 1985; Pollack, 2013), microtubular dipole fields (Jibu & Yasue, 1995; Hameroff & Penrose, 2014), cytoskeletal vibrational modes (Fröhlich, 1968), excitonic mitochondrial dynamics (Nicholls & Ferguson, 2013), chromatin dipole oscillations (Montagnier et al., 2011; Bizzarri et al., 2013), and large-scale electromagnetic field patterns (Singer, 1999; McFadden, 2002; Vitiello, 2014).

Each substrate undergoes SSB, generating a distinct vacuum manifold and an associated set of Nambu–Goldstone modes (dipole-wave quanta, DWQ). These long-range modes support extended coherence and mediate cross-scale coupling.

On this basis, the organism can be represented by twelve coherence sectors Θ_1 – Θ_{12} :

- Θ_1 : foundational intracellular water and cytoskeletal coherence
- Θ_2 : immune and inflammatory coherence
- Θ_3 : homeostatic ionic and autonomic balance
- Θ_4 : interoceptive and vagal–enteric coherence
- Θ_5 : circulatory and motility coherence
- Θ_6 : mitochondrial metabolic coherence
- Θ_7 : regenerative and stem-cell-related coherence
- Θ_8 : chromatin and morphogenetic pattern coherence
- Θ_9 : circadian and restorative coherence
- Θ_{10} : cognitive–cortical coherence
- Θ_{11} : limbic and affective coherence

- Θ_{12} : global electromagnetic unity
- Each Θ -field corresponds to a condensation amplitude $\theta_k(t)$ derived from the underlying vacuum structure. The condensate densities $N_k = \sinh^2(\theta_k)$ quantify the degree of quantum coherence in each sector.
- The explicit physical–biological grounding of each field follows directly from its underlying substrate, allowing the model to integrate cellular, physiological, cognitive, and organism-wide electromagnetic dynamics in a single theoretical framework.

3.2. Quantum Substrates, Microscopic Variables, and Spontaneously Broken Symmetries of the Twelve Life Fields (Θ_1 – Θ_{12})

To anchor the Quantum Blueprint Formalism firmly within the dissipative quantum field theory (DQFT) framework, each Life Field Θ_k is understood as an effective symmetry-breaking sector characterized by:

1. Quantum substrates (microscopic carriers)
2. Field variables (operators)
3. Spontaneously broken symmetries (SSB)
4. An order parameter θ_k and its Goldstone-like modes

In this view, the organism is described by a twelve-dimensional manifold of ordered vacua, with dynamics governed by the evolution of the order parameters θ_1 – θ_{12} . These SSB sectors are not intended as fundamental fields in the Lagrangian sense, but as coarse-grained, phenomenological condensate sectors in the DQFT spirit of Del Giudice and Vitiello.

Θ_1 – Foundation

Cellular Ground-State Coherence

Quantum substrates

- Intracellular water DWQ
- Membrane potential dipoles
- ETC electron-/proton excitons
- Cytosolic phonon-like modes
- Basal microtubule dipole coherence

Field variables

$P(r), V_{\text{mem}}(r), \psi_{\text{ETC}}(r), u(r), M_{\text{MT}}(r)$

Broken symmetries

- $U(1)$ phase symmetry of the water–EM dipole field
- Rotational symmetry in dipole orientation

Order parameter & Goldstone modes

θ_1 ; long-wavelength polarization waves in DWQ domains

Θ_2 – Protection

Immune–Inflammatory Coherence

Quantum substrates

- Quantum two-state receptor conformations
- Lymphatic DWQ
- Actin soliton waves in immune cells

Field variables

$\sigma_i, P_{\text{lymph}}(r), \varphi_{\text{actin}}(r)$

Broken symmetries

- Z_2 symmetry of receptor-state configurations
- $U(1)$ phase symmetry of lymphatic DWQ

Order parameter & Goldstone modes

θ_2 ; low-frequency conformational and actin-phase modes supporting immune coherence

Θ_3 – Balance

Electrolytic, pH, and Autonomic–Vascular Homeostasis

This field emphasizes electrolytic equilibrium as central for autonomic stability.

Quantum substrates

- Coherent Ca^{2+} , K^+ , Na^+ , H^+ (pH) oscillatory fields
- Smooth muscle Davydov-type solitons
- Plasma-water polarization DWQ
- Endothelial electrochemical oscillators

Field variables

$\varphi_{ion}(r)$ for $Ca^{2+}/K^+/Na^+/H^+$; $P_{plasma}(r)$; $\varphi_{smooth}(r)$

Broken symmetries

- $U(1)$ phase symmetry of ionic oscillators
- Approximate translational symmetry in vascular networks
- Effective $U(1)$ -type symmetry associated with electrochemical potentials (broken by steady-state ionic gradients)

Order parameter & Goldstone modes

θ_3 ; propagating electrochemical phase waves governing baroreflex stability and vascular tone

Θ_4 – Centeredness

Vagal Interoception, Gut–Brain Axis, Enteric DWQ, and Microbiome-Modulated Coherence

This field integrates vagal afferents, enteric DWQ, gut–brain-axis coupling, and microbiome-modulated dynamics.

Quantum substrates

- Vagal microtubule dipole fields
- Enteric water DWQ and mucosal dipole layers
- Piezoelectric baroreceptor and mechanoreceptor fields
- Microbiome-derived metabolic and redox oscillations that modulate DWQ and EM substrates (e.g., butyrate, lactate, indole-related metabolites)
- Gut epithelial microtubule and membrane potentials

Field variables

$M_{vagus}(r)$, $P_{enteric}(r)$, $Q_{barorec}(r)$, $M_{microbio}(r)$, $\varphi_{GBA}(r)$

Broken symmetries

- $U(1)$ vagal–enteric phase symmetry
- Rotational dipole symmetry of microtubules and enteric DWQ
- Approximate metabolic symmetry of the gut–microbiome ensemble (broken by coherent preference patterns)

Order parameter & Goldstone modes

θ_4 ; coherent vagal–gut-phase modulation waves, microbiome–GBA phase entrainment, and interoceptive prediction-like waves

Θ_5 – Flow

Circulatory and Locomotor Coherence

Quantum substrates

- Actomyosin excitons
- Cardiac microtubule dipoles
- Blood-plasma DWQ

Field variables

 $\psi_{\text{acto}}(r)$, $M_{\text{heart}}(r)$, $P_{\text{blood}}(r)$

Broken symmetries

- Approximate translational symmetry along muscular fibers
- U(1) phase symmetry of contraction oscillators

Order parameter & Goldstone modes

 θ_5 ; cardiac and myofascial contractile-phase shifts and their associated propagating coherence modes Θ_6 – Vitality

Mitochondrial Electron–Proton Coherence

Quantum substrates

- ETC electron excitons
- Proton oscillatory modes across the inner mitochondrial membrane
- Mitochondrial DWQ domains

Field variables

 $\psi_{\text{ETC}}(r)$, $\varphi_{\text{H}^+}(r)$, $P_{\text{mito}}(r)$

Broken symmetries

- U(1) phase symmetry of the ETC electron–proton system
- Effective gauge-like symmetry associated with the electrochemical potential

Order parameter & Goldstone modes

 θ_6 ; ETC phase fluctuations and coherent bioenergetic waves Θ_7 – Renewal

Regeneration and Turnover

Quantum substrates

- DWQ condensates in stem-cell niches
- DNA vibrational modes
- ECM piezoelectric modes

Field variables

 $P_{\text{SC}}(r)$, $\varphi_{\text{DNA}}(r)$, $Q_{\text{ECM}}(r)$

Broken symmetries

- Chromatin conformational symmetry
- ECM mechanical symmetry (translational and rotational invariances)

Order parameter & Goldstone modes

 θ_7 ; soft chromatin–ECM remodeling modes underlying regenerative coherence

Θ_8 – Blueprint

Epigenetic Architecture and Fascia

Quantum substrates

- Chromatin excitons
- DNA base-pair dipoles
- Hydration-shell DWQ
- Collagen piezoelectric fields
- Fascial liquid-crystal ordering
- Coherent fascial water

Field variables

 $\psi_{\text{chrom}}(r), d_{\text{bp}}(r), P_{\text{hydr}}(r), Q_{\text{coll}}(r), n_{\text{fascia}}(r), P_{\text{fascia}}(r)$

Broken symmetries

- U(1) chromatin dipole symmetry
- O(3) rotational symmetry of fascia broken to O(2) (selection of a director in collagen/fascial alignment)
- ECM translational symmetry

Order parameter & Goldstone modes

 Θ_8 ; fascia director waves and chromatin soft modes representing morphogenetic “blueprint” coherence
 Θ_9 – Restoration

Sleep and Circadian Coherence

Quantum substrates

- Pineal microtubules
- Molecular circadian oscillators
- Thalamo–cortical DWQ

Field variables

 $M_{\text{pineal}}(r), \varphi_{\text{circ}}(i), P_{\text{TC}}(r)$

Broken symmetries

- U(1) circadian phase symmetry
- Time-translation symmetry (broken by persistent circadian rhythmicity)

Order parameter & Goldstone modes

 Θ_9 ; circadian phase drift and sleep-cycle transitions as low-energy phase modes in the restoration sector
 Θ_{10} – Clarity

Cognitive Integration

Quantum substrates

- Cortical microtubule dipoles
- Astrocytic Ca^{2+} waves
- Cortical EM field modes

Field variables

 $M_{\text{cortex}}(r), \varphi_{\text{astro}}(r), A_{\text{cortex}}(r)$

Broken symmetries

- U(1) cortical EM phase symmetry
- Approximate permutation/rotational symmetry among cortical assemblies (broken by phase-locked functional networks)

Order parameter & Goldstone modes
 θ_{10} ; cortical microstate transitions and coherence shifts underlying cognitive integration

Θ_{11} – Emotion

Limbic–Affective Coherence

- Quantum substrates
- Limbic microtubule dipoles
 - Limbic DWQ
 - Emotion-associated EM oscillations

Field variables

$M_{\text{limb}}(r)$, $P_{\text{limb}}(r)$, $A_{\text{limb}}(r)$

- Broken symmetries
- U(1) limbic-phase symmetry
 - Possible non-compact group symmetries consistent with SU(1,1)-type coherent-state structures in affective networks (conjectural)

Order parameter & Goldstone modes
 θ_{11} ; slow attractor transitions in emotional phase space (limbic coherence modes)

Θ_{12} – Unity

Global Systemic Coherence

- Quantum substrates
- Whole-brain EM field
 - Heart–brain SU(1,1)-type coupling
 - Whole-body DWQ condensate

Field variables

$A_{\text{global}}(r)$, $u(r)$, $P_{\text{body}}(r)$

- Broken symmetries
- SU(1,1) coherence symmetry (coherent-state algebra)
 - Global U(1) phase symmetry of large-scale EM modes

Order parameter & Goldstone modes
 θ_{12} ; global phase-drift modes across physiological networks representing whole-system coherence (“Unity” sector)

Synthesis

Together, the twelve Life Fields constitute a twelve-sector SSB architecture, each with its own quantum substrates, order parameter θ_k , and Goldstone-like coherence modes. They define a twelve-dimensional manifold of ordered vacua, with biological function corresponding to motion on this manifold.

3.3. Macroscopic Evolution Equation for the Coherence Fields

The temporal evolution of each condensation amplitude $\theta_k(t)$ is obtained by projecting the doubled Liouville equation onto the manifold of coherent vacua $|0(\Theta(t))\rangle$ (Breuer & Petruccione, 2002; Celeghini et al., 1992). Under time-scale separation, this yields an effective dynamical law:

- $$d\theta_k/dt = -\gamma_k (\theta_k - \theta_{k_ref}) + \sum_j \Lambda_{kj} \cdot G_{kj}(\theta_{k'}, \theta_j) + I_k(t) + \xi_k(t).$$

Here:

 - $\gamma_k > 0$ is the intrinsic relaxation rate toward the free-energy minimum,

- θ_{k_ref} is the attractor value determined by $\partial \mathcal{F} / \partial \theta_k = 0$ (Takahashi & Umezawa, 1975; Vitiello, 1995),
- Λ_{kj} represents cross-field coupling coefficients (e.g., metabolism $\rightarrow$ immunity $\rightarrow$ autonomic regulation),
- $G_{kj}(\theta_k, \theta_j)$ encodes nonlinear interdependence,
- $I_k(t)$ represents external driving (pressure, sensory input, EM fields),
- $\xi_k(t)$ captures stochastic fluctuations of unresolved microscopic modes.

This equation describes the organism’s movement through its twelve-dimensional vacuum manifold, where functional states correspond to regions around distinct free-energy minima.

A detailed derivation is given in Appendix A.

3.4. Free-Energy Landscape and the Organismic Attractor Θ_ref

The full organismic coherence state is determined by the free-energy functional

$$\mathcal{F}(\Theta) = \sum_k F_k(\theta_k) + \sum_{k < j} C_{kj}(\theta_k, \theta_j),$$

where $F_k(\theta_k)$ reflects the cost of maintaining coherence in field θ_k , and C_{kj} describes cross-field energetic coupling (e.g., immune–metabolic interactions; see Franceschi & Campisi, 2014).

The attractor state is defined by the stationarity conditions:

$$\partial \mathcal{F} / \partial \theta_k = 0, \text{ for all } k.$$

The solution

$$\Theta_ref = \{ \theta_{1_ref}, \dots, \theta_{12_ref} \}$$

defines the global coherence configuration toward which $\Theta(t)$ relaxes.

This attractor corresponds phenomenologically to stable physiological states including:

- metabolic equilibrium (Nicholls & Ferguson, 2013),
- circadian synchrony (Roenneberg et al., 2007),
- heart–brain coherence (McCraty et al., 2009),
- stable cognitive phase locking (Singer, 1999),
- emotional integration (Pockett, 2012).

Small perturbations cause excursions in $\theta_k(t)$, but the system returns to Θ_ref unless pushed across a bifurcation threshold. Appendix A provides the mathematical foundation for this gradient-flow structure.

3.5. The Biological Coherence Index (BCI)

The Biological Coherence Index maps the theoretical order parameters $\Theta(t)$ to experimentally accessible observables. To quantify the proximity of the instantaneous vacuum $|0(\Theta(t))\rangle$ to the attractor $|0(\Theta_ref)\rangle$, we use the vacuum overlap

$$C(\Theta(t), \Theta_ref) = \langle 0(\Theta_ref) | 0(\Theta(t)) \rangle.$$

For small deviations $\Delta\theta_k = \theta_k(t) - \theta_{k_ref}$, the overlap is

$$C \approx \exp(-\frac{1}{2} \sum_k (\Delta\theta_k)^2).$$

To allow domain-specific weighting, we define:

$$BCI(t) = \exp(-\frac{1}{2} \sum_k w_k (\theta_k(t) - \theta_{k_ref})^2),$$

where w_k adjusts the contribution of each field (e.g., θ_6 for metabolism; θ_{10} for cognition). This index yields a scalar value 0–1 representing whole-organism coherence.

Appendix B provides the derivation of this expression from the vacuum overlap formula.

3.6. Model Predictions

The multi-field dissipative framework yields several experimentally testable predictions:

1. Cross-scale entrainment:
Coherence in θ_6 (metabolism) modulates θ_2 (immunity), consistent with metabolic–immune coupling (Franceschi & Campisi, 2014).

2. Frequency-selective susceptibility:
Linearization of the dynamical equation yields susceptibilities
 $\chi_k(\omega) = 1 / (\gamma_k + i\omega)$,
predicting field-specific response windows (Singer, 1999; Pilla, 2013).
3. Coherence collapse:
Perturbations that distort $\Theta(t)$ away from Θ_{ref} reduce BCI(t), potentially corresponding to stress-induced dysregulation.
4. Restorative reintegration:
Recovery toward Θ_{ref} during sleep (Θ_9) should coincide with increases in BCI and in physiological synchrony (Roenneberg et al., 2007).
5. Fractal signatures:
High-coherence states exhibit increased fractal scaling in physiological data (Goldberger et al., 2002), consistent with multi-level vacuum alignment.

4. Discussion and Conclusion

The multi-field dissipative quantum framework developed in this work provides a unified approach to understanding long-range coherence and integrative dynamics across biological scales. The central result is that biological organization can be represented as a twelve-dimensional manifold of coherent vacua, each vacuum sector arising from the spontaneous symmetry breaking (SSB) of a specific quantum substrate. This structure combines insights from dissipative quantum field theory (DQFT) (Celeghini, Rasetti & Vitiello, 1992; Umezawa, 1993; Blasone, Jizba & Vitiello, 2011), water-coherence theory (Del Giudice et al., 1985; Pollack, 2013), microtubule dipole models (Jibu & Yasue, 1995; Hameroff & Penrose, 2014), excitonic bioenergetics (Nicholls & Ferguson, 2013; Wallace, 2010), chromatin vibrational dynamics (Montagnier et al., 2011; Bizzarri et al., 2013), and organism-wide electromagnetic synchronization (Singer, 1999; Freeman, 2000; Vitiello, 2014).

4.1. Dissipative Structure and Biological Integration

Biological systems are inherently dissipative, exchanging energy and entropy with the environment at multiple timescales (Prigogine, 1980; Breuer & Petruccione, 2002). In the DQFT formalism, dissipation is represented intrinsically through the doubling of operators ($\hat{a}_k, \tilde{a}_k$), ensuring that coherence does not contradict thermodynamic irreversibility. This structural feature is crucial for explaining why living systems are able to maintain non-equilibrium coherent states rather than relaxing to equilibrium.

The multi-field architecture illustrates that coherence in biological organisms is not governed by a single dominant process, but by interacting layers of quantum substrates, each associated with a different physiological domain. For example, metabolic coherence (Θ_6) and immune coherence (Θ_2) interact strongly (Franceschi & Campisi, 2014), as do cognitive (Θ_{10}) and emotional (Θ_{11}) coherence fields (McCraty et al., 2009; Pockett, 2012). The model provides a mathematically explicit and biologically interpretable explanation for such cross-scale entrainment.

4.2. Vacuum Manifold and Functional States

Because distinct condensation patterns θ_k define unitarily inequivalent vacua, each physiological state corresponds to a specific region of the vacuum manifold. Changes in environmental or internal conditions—light, metabolic load, stress, sensory input, sleep pressure—move the system through the manifold toward or away from the free-energy minimum Θ_{ref} . This formalism explains:

- how coherent states (e.g., restorative sleep, metabolic equilibrium) arise from low free-energy configurations,
- how dysregulation and decoherence correspond to perturbations away from Θ_{ref} ,

- why certain physiological transitions are abrupt, reflecting transitions between neighboring vacuum sectors, similar to phase transitions.

These features resonate with known properties of biological rhythms and coherence dynamics (Roenneberg et al., 2007; Goldberger et al., 2002).

4.3. Long-Range Coupling via Dipole-Wave Quanta

The presence of Nambu–Goldstone–like dipole-wave quanta (DWQ) is essential: these massless collective oscillations enable nonlocal coupling within and between coherence fields. DWQ propagation through structured water, cytoskeletal networks, and tissue-level EM fields provides a physical mechanism for long-range synchronization seen in:

- intracellular water domains (Del Giudice et al., 1985),
- microtubular systems (Jibu & Yasue, 1995; Tuszyński et al., 1995),
- large-scale electromagnetic brain fields (Singer, 1999; Freeman, 2000),
- cross-organ interactions such as heart–brain coherence (McCraty et al., 2009).

This mechanism complements and extends classical signaling pathways without contradicting them.

4.4. Biological Coherence Index and experimental accessibility

The Biological Coherence Index (BCI), derived from vacuum overlap expressions (Appendix B), provides a theoretical bridge to measurable physiology. The BCI predicts that alignment across coherence fields coincides with distinctive empirical signatures such as:

- increased HRV coherence (Shaffer & Ginsberg, 2017),
- gamma-band synchronization (Singer, 1999),
- restored circadian phase-locking (Roenneberg et al., 2007),
- fractal scaling in physiological signals (Goldberger et al., 2002).

Because $\text{BCI}(t)$ reduces to a multidimensional Gaussian metric around Θ_{ref} , it can be estimated from multimodal biosignals using existing techniques in nonlinear dynamics and EM field analysis.

4.5. Implications and Future Directions

This modeling framework establishes a principled theoretical basis for integrative physiology. The multi-field DQFT architecture:

1. unifies coherence phenomena across biological scales,
2. clarifies the role of dissipation in maintaining order,
3. explains multi-stability and state transitions via vacuum dynamics,
4. predicts measurable coherence patterns across domains,
5. suggests new empirical investigations—e.g., coherence perturbations, resonance effects, and cross-modal entrainment.

Future work may involve:

- computational simulations of the dynamical equations for $\theta_k(t)$,
- experimental tests of cross-field susceptibility spectra ($\chi_k(\omega)$),
- multimodal BCI estimation in physiological or cognitive tasks,
- mapping pathological states as distortions of the vacuum manifold,
- exploring intervention strategies to shift $\Theta(t)$ toward Θ_{ref} .

4.6. Conclusion

We presented a dissipative quantum field model of whole-organism coherence in which twelve substrate-derived coherence fields interact through a shared free-energy landscape. Each field emerges from spontaneous symmetry breaking in a specific biological quantum substrate and

evolves according to macroscopic dynamical equations derived from DQFT. The vacuum manifold formed by these fields provides a unifying mathematical structure for multi-scale integration in biological systems. The model is compatible with known biophysical phenomena and yields testable predictions for future studies in systems biology and integrative physiology.

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Appendix A – Derivation of the Macroscopic Dynamics from the Doubled Liouville Equation

The macroscopic evolution equations for the coherence fields Θ_1 – Θ_{12} arise from a projection of the microscopic quantum dynamics onto the manifold of coherent vacua. This appendix provides a concise derivation based on the dissipative quantum field theoretical (DQFT) structure.

A.1 The Liouville–von Neumann Equation in the Doubled Hilbert Space

In DQFT, the state of the organism plus environment is represented by a density operator $\rho(t)$ acting on the doubled Hilbert space

$$H_{total} = H \otimes H,$$

where the “tilde” sector H encodes environmental and dissipative degrees of freedom (Umezawa, 1993; Celeghini et al., 1992).

The microscopic time evolution is given by the doubled Liouville–von Neumann equation:

$$d\rho/dt = -i [H_{total} , \rho],$$

with $H_{total} = H - H$.

This equation is exact, but its full content is not required to describe macroscopic coherence dynamics.

A.2 Order Parameters as Expectation Values

To extract macroscopic dynamics, we define a set of coarse-grained observables O_k associated with the coherence fields Θ_k . Their expectation values define the macroscopic order parameters:

$$\theta_k(t) = \text{Tr}[\rho(t) \cdot O_k].$$

Differentiating with respect to time and using the Liouville equation yields:

$$\begin{aligned} d\theta_k/dt &= \text{Tr}[(d\rho/dt) O_k] \\ &= -i \text{Tr}[\rho \cdot [O_k , H_{total}]] \\ &= \langle i [H_{total} , O_k] \rangle. \end{aligned}$$

This equation is exact but still depends on the full microscopic state $\rho(t)$.

A.3 Projection onto the Manifold of Coherent Vacua

The DQFT vacuum associated with a condensation pattern $\theta = \{\theta_1, \dots, \theta_{12}\}$ is given by:

$$|0(\theta)\rangle = \Pi_k [1 / \cosh(\theta_k)] \cdot \exp(\tanh(\theta_k) \hat{a}_k^\dagger \tilde{a}_k^\dagger) |0\rangle.$$

The evolution of the organism is approximated as motion within this manifold:

$$\rho(t) \approx |0(\theta(t))\rangle\langle 0(\theta(t))| + \text{fluctuations}.$$

To formalize this, we introduce the projection operator:

$$P X = |0(\theta(t))\rangle\langle 0(\theta(t))| X |0(\theta(t))\rangle\langle 0(\theta(t))|.$$

The complementary operator $Q = 1 - P$ isolates fast microscopic fluctuations.

Using the Mori-Zwanzig projection operator formalism (Breuer & Petruccione, 2002), the projected evolution satisfies:

$$d(PQ)/dt = P L P Q + P L Q Q,$$

where L is the Liouvillian: $L X = -i [H_{\text{total}}, X]$.

Under the standard assumptions of:

1. time-scale separation between slow (θ_k) and fast fluctuations,
2. rapid decay of memory terms (Markov limit),

the projected dynamics become:

$$d\theta_k/dt = A_k(\theta) + \xi_k(t),$$

where $A_k(\theta)$ depends only on the macroscopic variables and $\xi_k(t)$ accounts for noise from $Q Q$.

A.4 Free-Energy Gradient and Relaxation Dynamics

The free-energy functional associated with the vacuum $|0(\theta)\rangle$ is defined as:

$$\mathcal{F}(\theta) = \langle 0(\theta) | H_{\text{total}} - (1/\beta) S | 0(\theta) \rangle,$$

where S is the entropy operator intrinsic to the operator-doubling formalism (Takahashi & Umezawa, 1975).

At the free-energy minimum Θ_{ref} we have:

$$\partial \mathcal{F} / \partial \theta_k = 0.$$

Expanding $\mathcal{F}(\Theta)$ around Θ_{ref} :

$$\mathcal{F}(\Theta) \approx \mathcal{F}(\Theta_{\text{ref}})$$

$$+ \frac{1}{2} \sum_{kj} (\theta_k - \theta_{k_{\text{ref}}}) K_{kj} (\theta_j - \theta_{j_{\text{ref}}}),$$

where K_{kj} is the Hessian matrix of $\partial^2 \mathcal{F} / \partial \theta_k \partial \theta_j$ evaluated at Θ_{ref} .

In this regime, the drift term satisfies:

$$A_k(\theta) \approx - \sum_j K_{kj} (\theta_j - \theta_{j_{\text{ref}}}).$$

This gives the macroscopic relaxation law:

$$d\theta_k/dt = - \gamma_k (\theta_k - \theta_{k_{\text{ref}}}) + \sum_j \Lambda_{kj} \cdot G_{kj}(\theta_k, \theta_j) + \xi_k(t),$$

where:

- $\gamma_k \approx K_{kk}$ is the intrinsic relaxation rate,
- Λ_{kj} and G_{kj} encode cross-field nonlinear coupling,
- $\xi_k(t)$ represents residual noise from fast microscopic variables.

This is the equation used throughout the main text.

A.5 External Forcing and Linear Susceptibility

If the system experiences a weak external input $I_k(t)$ via perturbation of the Hamiltonian:

$$H_{\text{total}} \rightarrow H_{\text{total}} + I_k(t) V_k,$$

the response of $\theta_k(t)$ obeys:

$$d(\delta\theta_k)/dt + \gamma_k \delta\theta_k \approx I_k(t).$$

For a harmonic perturbation $I_k(t) = I_0 e^{i\omega t}$, the steady-state response is:

$$\delta\theta_k(\omega) = \chi_k(\omega) \cdot I_0,$$

where the susceptibility is:

$$\chi_k(\omega) = 1 / (\gamma_k + i\omega).$$

This prediction provides an experimentally testable link between the theoretical coherence fields and measurable physiological inputs (e.g., EM stimulation frequencies).

Summary

Appendix A shows that the macroscopic evolution of each coherence field Θ_k follows from:

1. the microscopic Liouville dynamics,

2. projection onto the vacuum manifold,
3. free-energy minimization, and
4. the gradient-flow structure of $\mathcal{F}(\Theta)$.

The resulting equation captures relaxation, coupling, noise, and susceptibility—precisely the features required to model biological coherence across scales.

Appendix B – Derivation of the Biological Coherence Index (BCI)

The Biological Coherence Index (BCI) provides a scalar measure of the proximity of the organism's instantaneous coherence configuration $\Theta(t)$ to the reference attractor configuration Θ_{ref} . This appendix derives the BCI from the overlap between coherent vacua in the dissipative quantum field theory (DQFT) framework.

B.1 Vacuum Overlap in Dissipative Quantum Field Theory

Each set of condensation amplitudes $\theta = \{\theta_1, \dots, \theta_{12}\}$ defines a coherent vacuum state of the form $|0(\theta)\rangle = \prod_k [1 / \cosh(\theta_k)] \cdot \exp(\tanh(\theta_k) \cdot \hat{a}_k^\dagger \hat{a}_k^\dagger) |0\rangle$.

Given two coherent vacua, for instance the instantaneous vacuum $|0(\Theta(t))\rangle$ and the reference vacuum $|0(\Theta_{\text{ref}})\rangle$, their overlap is

$$C(\Theta(t), \Theta_{\text{ref}}) = \langle 0(\Theta_{\text{ref}}) | 0(\Theta(t)) \rangle.$$

Because condensation patterns define unitarily inequivalent vacua in the infinite-mode limit, small deviations $\Delta\theta_k = \theta_k(t) - \theta_{k,\text{ref}}$ lead to exponential suppression of C .

B.2 Factorization and Small-Deviation Approximation

For independent modes, the overlap factorizes:

$$C(\Theta(t), \Theta_{\text{ref}}) = \prod_k [1 / \cosh(\Delta\theta_k)].$$

For small deviations $\Delta\theta_k \ll 1$, the hyperbolic cosine is approximated by

$$\cosh(\Delta\theta_k) \approx \exp(\Delta\theta_k^2 / 2),$$

leading to

$$1 / \cosh(\Delta\theta_k) \approx \exp(-\Delta\theta_k^2 / 2).$$

Thus the full overlap becomes

$$C(\Theta(t), \Theta_{\text{ref}}) \approx \exp(-\frac{1}{2} \sum_k \Delta\theta_k^2).$$

The squared magnitude of the overlap, relevant for coherence measures, is

$$|C(\Theta(t), \Theta_{\text{ref}})|^2 \approx \exp(-\sum_k \Delta\theta_k^2).$$

This expression quantifies how close the current vacuum is to the reference vacuum in terms of the underlying condensation amplitudes.

B.3 Weighted Biological Coherence Index

Not all coherence fields contribute equally to systemic physiological integration. To incorporate domain-specific weighting, we introduce non-negative coefficients $w_k > 0$. This yields a generalized index:

$$\text{BCI}(t) = \exp(-\frac{1}{2} \sum_k w_k \cdot (\theta_k(t) - \theta_{k,\text{ref}})^2).$$

This form preserves the Gaussian nature of the vacuum-overlap metric while allowing biological relevance, functional importance, or measurement sensitivity of each field to be encoded through w_k .

B.4 Interpretation

The BCI is a scalar in $[0, 1]$:

- $\text{BCI} = 1$ corresponds to perfect alignment with the attractor vacuum Θ_{ref} .
- $\text{BCI} \rightarrow 0$ indicates coherence breakdown, large deviation from Θ_{ref} , or multi-field desynchronization.

Because $\theta_k(t)$ can be estimated indirectly from physiological signals—such as HRV coherence, EEG phase synchronization, mitochondrial potential, circadian markers, or dielectric water signatures—the BCI provides a theoretically grounded and experimentally accessible measure of organismic coherence.

Appendix C – Minimal Spontaneous Symmetry Breaking Model for Dipole-Wave Quanta

This appendix presents a minimal field-theoretic model illustrating how spontaneous symmetry breaking (SSB) in a dipolar biological substrate generates long-range collective excitations known as dipole-wave quanta (DWQ). These excitations arise as Nambu–Goldstone modes associated with broken continuous symmetries and provide a physical mechanism for extended biological coherence.

C.1 Lagrangian and Symmetry

Consider a complex dipole field $\psi(x)$ representing collective oscillations of biological dipoles such as water molecules, microtubular dimers, chromatin dipole stacks, or ionic phase domains. The field is assumed to possess a global U(1) symmetry:

$$\psi(x) \rightarrow e^{i\alpha} \psi(x).$$

A minimal Lagrangian capturing the dynamics of this field is

$$L = \partial_m \psi^*(x) \partial^m \psi(x) - V(|\psi(x)|^2),$$

with a symmetry-breaking potential of the form

$$V(|\psi|^2) = -\mu^2 |\psi|^2 + \lambda |\psi|^4,$$

where $\mu^2 > 0$ and $\lambda > 0$.

This “Mexican-hat” potential favors a non-zero amplitude of ψ while preserving U(1) phase symmetry.

C.2 Vacuum Structure and Spontaneous Symmetry Breaking

Writing $r = |\psi|$, the potential becomes

$$V(r) = -\mu^2 r^2 + \lambda r^4.$$

Its extrema satisfy

$$dV/dr = -2\mu^2 r + 4\lambda r^3 = 0,$$

yielding the non-trivial minimum

$$r = v = \mu / \sqrt{2\lambda},$$

while $r = 0$ corresponds to an unstable symmetric vacuum.

The set of minima is parameterized by

$$\psi_0 = v e^{i\theta_0},$$

with $\theta_0 \in [0, 2\pi)$, forming a degenerate vacuum manifold. Selecting one phase θ_0 breaks the U(1) symmetry spontaneously.

C.3 Field Expansion and Quadratic Lagrangian

To analyze excitations around a chosen vacuum, we decompose the field as

$$\psi(x) = (v + h(x)) e^{i\varphi(x)},$$

where:

- $h(x)$ is the radial (amplitude) fluctuation,
- $\varphi(x)$ is the phase (Goldstone) fluctuation.

The derivative of ψ is

$$\partial_m \psi = [\partial_m h + i(v + h) \partial_m \varphi] e^{i\varphi}.$$

The kinetic term becomes

$$\begin{aligned} \partial_m \psi^* \partial^m \psi \\ = (\partial_m h)(\partial^m h) + (v + h)^2 (\partial_m \varphi)(\partial^m \varphi). \end{aligned}$$

Expanding the potential to second order in h :

$$(v + h)^2 = v^2 + 2 v h + h^2$$

$$(v + h)^4 = v^4 + 4 v^3 h + 6 v^2 h^2 + \dots$$

Inserting these into V gives

$$V(v + h) \approx \text{constant} + 4 \lambda v^2 h^2,$$

because the linear term cancels at the minimum where $\mu^2 = 2\lambda v^2$.

Thus the effective quadratic Lagrangian is

$$L_{\text{eff}} \approx (\partial_m h)(\partial^m h)$$

$$+ v^2 (\partial_m \varphi)(\partial^m \varphi)$$

$$- 4 \lambda v^2 h^2.$$

This expression contains two distinct excitations:

1. A massive radial mode $h(x)$ with effective mass $m_h^2 = 8 \lambda v^2$.
2. A massless phase mode $\varphi(x)$ with no mass term.

C.4 Dipole-Wave Quanta

The equation of motion for $\varphi(x)$ derived from L_{eff} is

$$\partial_m \partial^m \varphi(x) = 0.$$

Thus $\varphi(x)$ obeys the massless wave equation whose quanta are Nambu–Goldstone modes. In biological dipole systems, these excitations correspond to dipole-wave quanta (DWQ). Their defining properties include:

- negligible effective mass,
- long correlation lengths,
- propagation of coherent phase information,
- sensitivity to boundary conditions and environmental fluctuations.

DWQ provide a mechanism for long-range biological coherence in systems such as:

- coherent water domains (Del Giudice et al., 1985; Del Giudice et al., 1988),
- microtubule dipole networks (Jibu & Yasue, 1995; Hameroff & Penrose, 2014),
- chromatin hydration structures (Montagnier et al., 2011),
- organism-wide electromagnetic fields (Vitiello, 2014).

C.5 Integration into the Multi-Field Coherence Model

Each biological coherence sector Θ_k introduced in Section 3 corresponds to a specific quantum substrate whose collective degrees of freedom can be modeled by fields $\psi_k(x)$ of the type described above. Each substrate possesses:

- its own symmetry G_k ,
- a broken subgroup H_k ,
- a vacuum manifold G_k/H_k ,
- a Goldstone mode $\varphi_k(x)$, and
- a condensation amplitude $\theta_k(t)$.

The twelve coherence fields Θ_1 – Θ_{12} thus arise from twelve substrate-specific SSB processes generating DWQ_k. These DWQ mediate cross-scale coupling and stabilize coherent physiological states through the free-energy dynamics described in the main text.

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