Reviews

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A Review of the Results Obtained over Ten Years of Research on the Relaxation Response and its Quantum Field Theory Framework

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Abstract

In this work, we present a brief overview of our research on the Relaxation Response (RR) in healthy subjects and in patients with myocardial infarction. The practice of techniques employed to elicit the RR is associated with the laboratory observation of very rapid and uniform changes in a multitude of molecular species. As far as we know, no literature exists on the temporal dynamics of these changes in terms of simple stochastic diffusive processes or by Coulomb-type electrostatic interactions alone. The results we observed suggest, as a working hypothesis, a description in terms of collective coherent behavior of microscopic components, a description generally and successfully adopted in modern many-body physics. We therefore turned to consider the environment in which the molecules we have studied are embedded, namely, water. We examined several water electrodynamic properties in relation to a theoretical model that may account for its state changes and possible interactions with solutes. From this framework, a plausible view of the living system is the one in which the relationships among the parts, i.e., their collective coherent behavior, rather than the individual components themselves, may account for the manifestation of multiple properties (perception, language, semantic responsiveness to the environment, rather than mere "reaction"). Finally, our discussion leads us to the hypothesis that the heart may play a role in orchestrating the collective coherent behavior of the various parts and organs within the human body, and their rhythmic-functional stability.

Keywords: Relaxation Response; water; quantum electrodynamics; quantum field theory coherence

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Abbreviations

CD	coherent domain
EM	electromagnetic
EZ	exclusion zone
NG	Nambu-Goldstone
QED	quantum electrodynamics
QFT	quantum field theory
QM	quantum mechanics
RR	Relaxation Response

Introduction

The biophysical and biochemical properties of every living phenomenon arise from the relationships between the constituents of the system under analysis. In biology, the object of investigation is never the isolated single element, but the network of relations that connects it to the other elements.

By way of metaphor, one could say that our observations always occur through a narrow and indirect perspective—as if each molecule or particle studied "individually" served as a keyhole through which we observe the mechanisms in which it is involved. From this perspective, the biological world appears as a system of reflections, where every molecule and every cell acts as a mirror, reflecting the dynamics of the other elements with which it is in relation (Dal Lin, Romano, Iliceto, Tona, & Vitiello 2022).

The behavior (understood as function) of a system can therefore not be reduced to the mere arrangement of its structural parts; rather, it is a consequence of the intrinsic relationships among those parts. For example, it is not cholesterol *per se* that determines arterial occlusion or the onset of myocardial infarction, but rather the complex interactions among cholesterol, endothelial cells, hormones, cytokines, neurotransmitters, pollutants, toxins, and mental stressors. Similarly, the presence of a bacterium is not, in itself, sufficient to deterministically cause disease: the phenomenon of "infectious disease" requires a particular relationship among the bacterium, the host organism, the neuroendocrine-immune system, the level of mental stress, and the concurrence of other pathological conditions (Dal Lin, Stinco, & Migliorini 2023).

In this way, one can account for the individual variability in response to the same microbial agent: "pathogenicity" should therefore be understood as a property of the relationships among the different components involved in the phenomenon, rather than as an exclusive feature of a single element.

The reality observed through microscopic investigation thus appears as a fabric of discrete elements subject to oscillations (Rovelli 2020). Any attempt to isolate and deepen the static analysis of a system's components inevitably entails the loss of a dynamic, holistic view of their relationships. Conversely, the more a global perspective is adopted in the study of a phenomenon, the more one sacrifices precision in the analytical description of its subcomponents.

It is also well known that the quaternary structure of many proteins can undergo conformational changes in response to environmental interactions and, consequently, can perform different functional roles despite having the same primary sequence and genetic information (as occurs, for example, with hemoglobin and numerous enzymes).

As a result, the functional relationships among the components of a complex system are inseparable from the components themselves; indeed, the latter may change their appearance and configuration while maintaining their membership in a given relational pattern. Every living system preserves its overall equilibrium through continuous variations affecting its individual components.

Therefore, one cannot regard nature as a collection of closed systems: each element remains "open" both outwardly, in relation to the environment, and inwardly, with respect to the structures that constitute it, at different scales. From this perspective, in the physical and biological sciences, the concepts of "structure" and "function" are fundamentally inseparable (Vitiello 1998; 2001; 2024).

The implications of these principles are reflected in the interpretation of research findings on the effects of the Relaxation Response (RR), conducted for over 10 years in both healthy subjects and patients with myocardial infarction. The referenced bibliography presents the theoretical, experimental, and mathematical details. This paper summarizes the results on the RR in Section 1. It then addresses the fundamental concepts of quantum field theory (QFT), the motivations for its use in the study of biological systems, and the role of water in Sections 2 and 3. The mathematical details of our qualitative presentation of the QFT aspects are presented in the quoted literature. Our work then analyzes the formation of coherent domains (CDs) and their dynamics, involving tissues and other biological structures in Sections 4, 5 and 6, and the self-focusing of the electromagnetic (EM) field and the formation of microtubules in Sections 7 and 8. Section 9 is devoted to the heart–brain dialogue and concluding remarks.

The perspective resulting from the complex and multifaceted framework of the dynamics underlying biochemical activity accounts for the deeper origin of

the RR findings, which would otherwise be difficult to understand within a traditional mechanistic view.

1. Results of *In Vivo* and *In Vitro* Studies on the Relaxation Response

The perspective outlined above allows for conceiving human disease no longer as a process that can be reduced simply to the sum of "defective" or "pathogenic" elements, that is, to intrinsic causes, but rather as a phenomenon resulting from the complex network of relationships established among the parts of the system. Within this framework, "health" and "disease"—in the cases we have studied, myocardial infarction—appear as two aspects of the same reality: expressions of the (adaptive or maladaptive) interaction between the human biological system (understood as a psycho-physiological entity) and its environment. The term "ischemic heart disease" certainly has communicative and cognitive value, but it risks being limiting in therapeutic terms. Indeed, one cannot speak of "myocardial infarction" as an absolute entity; it takes shape in the particular life history of an individual, with their specific interactions, in a given context and at a particular moment. Each infarction event is therefore unique, as it results from the relationship between a subject's psychophysiology and their environment. At the basis of the phenomenon of "myocardial infarction" lies the individual who, over time, has constructed a network of relationships that are unfavorable to the maintenance of health equilibrium at different levels—from diet and physical activity to environmental and psychological factors. It is a widespread opinion that infarction is primarily related to excess cholesterol. However, the literature reports patients who develop infarction even in the presence of "normal" cholesterol levels (Tanabe, Tamachi, & Matsumoto 1980). Moreover, recurrent infarctions may occur even under conditions of "low" cholesterol despite specific therapies (Dal Lin *et al.* 2017b). It now appears that local coronary factors may determine the initiation and acceleration of the atherosclerotic process, such that "plaque begets plaque" (Soto-Mota 2025), irrespective of specific blood lipid levels. Indeed, a certain amount of dietary fats may even exert a protective effect against atherosclerosis (Zhou, Yiannakou, & Moore 2025). This suggests that not only the quantitative level of cholesterol ("high" or "low", "good" or "bad") is relevant, but, more importantly, the biochemical and contextual relationships in which cholesterol is embedded, which can influence its function and modify its biological quality, for example by favoring its oxidation or selective deposition in blood vessels. A holistic conception of the human organism, therefore, becomes essential, viewing it as an integrated system whose components interconnect across multiple levels of organization.

The psycho-emotional dimension plays a central role in this intrinsically interactive network. This is inseparable from cellular and molecular processes. Psychological stress is reflected at the somatic level through an interplay among neurotransmitters, hormones, and cytokines that affect lipid metabolism and vascular endothelial function (Dal Lin *et al.* 2015; Dal Lin, Tona, & Osto 2015). The disciplines of psychoneuroendocrinoimmunology (Ader 2011; Bottaccioli & Bottaccioli 2017) and epigenetics (Bottaccioli 2014) describe in detail how mental stress can constitute a primary cardiovascular risk factor (as well as for other chronic diseases) through pro-inflammatory and oxidative mechanisms (Dal Lin *et al.* 2017a; 2017b; 2017c; 2017d; Fioranelli *et al.* 2017; Piccoli *et al.* 2017).

If, therefore, a maladaptive relationship with the environment constitutes the premise, then restoring an adaptive relationship should promote health, as documented by numerous studies on diet and physical activity (Bottaccioli & Bottaccioli 2017). The psycho-emotional dimension, however, remains comparatively underexplored.

In any case, if mental stress promotes disease—as extensively documented (Pimple *et al.* 2015; Bottaccioli & Bottaccioli 2017; Fioranelli *et al.* 2018)—it is reasonable to assume that the promotion of relaxation fosters a state of health, in line with a well-established clinical and experimental tradition (Dal Lin, Ferrari *et al.* 2020).

In an attempt to elucidate the molecular bases of this phenomenon, our group initiated approximately ten years ago a series of studies on the Relaxation Response (RR) in both healthy subjects and patients after myocardial infarction. Various psychological techniques for attentional focusing produce a physiological state of relaxation. These include breath control, ideational meditation, meditation using the repetition of phonemes, prayer and similar practices (Benson, Beary, & Carol 1974; Benson 2006; Benson &

Proctor 2011). The set of biochemical and biophysical mechanisms (still under investigation) associated with these activities is referred to as the so-called Relaxation Response. In our research, we employed meditative techniques based on focused attention on breathing, listening to musical sounds, and the repetition of phonemes, for 20 minutes twice a day, for one year (Dal Lin, Marinova *et al.* 2018).

Figure 1 presents a summary of the main results. For further details, the reader is referred to the original publications.

The magnitude, uniformity, and rapidity of the

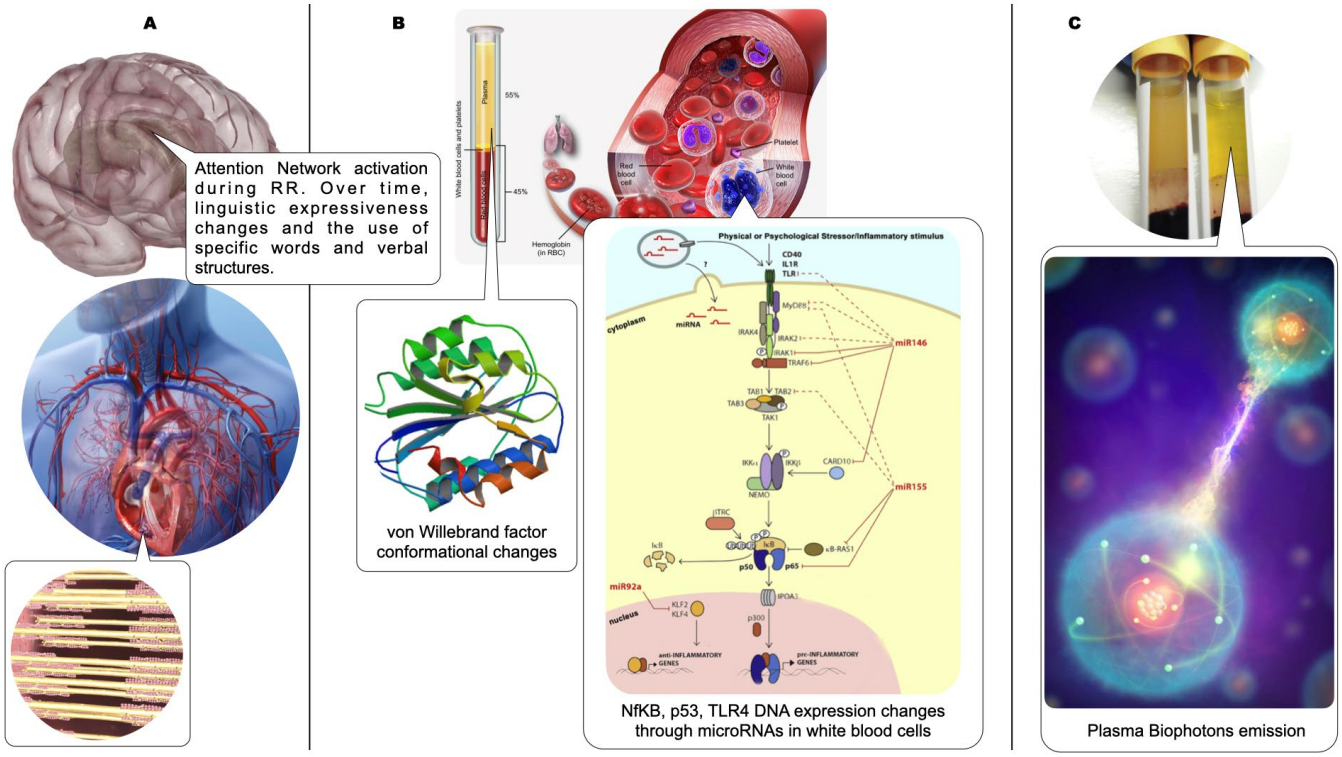

Figure 1. An artist's sketch illustrates the main results of our research on RR. During 20 minutes of RR practice, the following were documented: from top to bottom, A) a change in brain area activation, from the default mode network to the attention network (Malinowski 2013; Boccia, Piccardi, & Guariglia 2015); a reduction in heart rate, changes in cardiac volumes, body temperature, and blood pressure, a decrease in left ventricular ejection fraction at unchanged cardiac output, and an increase in coronary flow reserve (Dal Lin, Marinova *et al.* 2018). All these modifications alter the interaction between actin–myosin cross-bridges at the intracellular level in cardiac myocytes. B) In addition, decreases were observed in the levels of numerous stress hormones, inflammatory cytokines, and oxidative stress markers, as well as changes in the expression of the genes NfKB, TLR4, and p53 in leukocyte precursors (Dal Lin, Marinova *et al.* 2018). These processes occur through variations in the levels of certain circulating microRNAs (Dal Lin, Gola *et al.* 2018; Dal Lin, Marinova *et al.*, 2021) and in telomerase activity (Dal Lin, Marinova *et al.* 2021). A possible slowing of cellular senescence and ageing processes has also been reported (Pavanello *et al.* 2019; Dal Lin, Marinova *et al.* 2021). RR practice further induces changes in the carbonyl groups of plasma proteins and in von Willebrand factor polymers (Dal Lin, Acquasaliente *et al.* 2021), supporting the hypothesis of consequent conformational remodeling of proteins and the establishment of coherent dynamics in the surrounding water (Madl & Renati 2023). C) An increase in blood transparency has also been observed in subjects practicing RR. The real blood sample photo on the right was taken immediately after an RR session, and the one on the left was taken immediately before (Dal Lin, Gola *et al.* 2018; Dal Lin, Marinova *et al.* 2018; Dal Lin, Grasso *et al.* 2020; Dal Lin *et al.* 2021). Other biological parameters assessed included blood pH, plasma electrical conductivity, and ultraweak photo-induced light emission (biophotons), which persisted for several minutes after light irradiation of the samples (Dal Lin, Grasso *et al.* 2020). In every subject, reductions in plasma conductivity were detected, associated with a linear relationship between the logarithm of the energy emitted by biophotons and the oscillation frequency (Dal Lin, Grasso *et al.* 2020); this finding suggests the presence of coherent correlation among the elements of the blood.

molecular changes reported in our studies, as well as their reproducibility across different subjects followed over time, argue against explanations based solely on electrostatic, stochastic, or diffusive interactions among molecular components. Since plasma molecules carry electric charge and dipole moment, and are therefore sensitive to EM fields, one may hypothesize the onset of phase-locked, wave-like molecular motions induced by excitations of ambient dipole fields (a point to which we will return below). The improvement in subjective well-being and clinical conditions in patients suggests that RR practice is accompanied by immediate biochemical, molecular, and biophysical changes (Dal Lin *et al.* 2021). Furthermore, in the subjects studied, a change over time was observed in linguistic expressiveness and in the use of specific words and verbal structures (Dal Lin, Brugnolo *et al.* 2020), indicating a different perception of reality and an emotional and behavioral reorganization. These results are detailed in (Dal Lin, Brugnolo e*t al.* 2020); for further insights into general linguistic aspects, the reader is also referred to the work of Piattelli-Palmarini and Vitiello (Piattelli-Palmarini & Vitiello 2015; Piattelli-Palmarini & Vitiello 2017a; Piattelli-Palmarini & Vitiello, 2017b). Of particular interest is the finding that the auditory stimuli used to induce RR (phonemes and musical sounds) exhibit fractal structure (Dal Lin, Radu e*t al.* 2020; Dal Lin, Romano, Iliceto, Tona, & Vitiello 2022). Acoustic spectral analysis of these sounds has demonstrated their capacity to modulate the contractility of HL1 cardiomyocytes in culture, affecting cytoskeletal organization (Dal Lin, Radu e*t al.* 2020). This finding further corroborates the in vivo observations (Dal Lin, Marinova e*t al.* 2018), namely the improvement in cardiac performance during the practice of RR (Figure 1-A). Sound waves behave as pressure waves that can regulate cellular behavior through mechanotransduction (Wang, Tytell, & Ingber 2009).

We wish to reiterate a key point: the magnitude, uniformity, and rapidity of our experimental findings necessitated drawing on physics to explain the results. Stimulated by various comments from colleagues who read our aforementioned works, we now seek to elaborate and clarify—particularly for readers with a background in biology and chemistry—the theoretical physical framework employed in our studies.

2. Quantum Physics and Water in Biological Systems

Schrödinger, in his *What is Life?* (Schrödinger 1967 [1944]), observed that in biological systems the "regularities only in the average" (*Ibidem* p. 78), emerging from the statistical mechanisms are not enough to explain the "enigmatic biological stability" (*Ibidem* p. 47) and argued that the "expectation of the classical physicist (...) far from being trivial, is wrong" (*Ibidem* p. 19). He stressed that "...it needs no poetical imagination but only clear and sober scientific reflection to recognise that we are here obviously faced with events whose regular and lawful unfolding is guided by a mechanism entirely different from the probability mechanism of physics" (*Ibidem* p. 79). He thus suggested that a deeper understanding of living matter could arise from the use of quantum mechanics (QM) (of which he was one of the 'founding fathers'). Of course, Schrödinger's proposal did not deny the fundamental importance of traditional biochemical analysis. Such analysis remains *necessary*, but it is *not sufficient* to understand biological processes and their properties, including, in particular, their functional stability, which contrasts with the intrinsic randomness of (bio)chemical reactions.

Along similar lines, in subsequent years, Ilya Prigogine emphasized that biological systems are dissipative systems, i.e., in continuous exchange of energy and matter with the environment (Prigogine 1962; Prigogine & Nicolis 1977). Herbert Fröhlich (Fröhlich 1968) highlighted the highly peculiar behavior of water in biological systems and the specific conditions under which it operates, thereby giving concrete support to Schrödinger's argument regarding the insufficiency of a predominantly biochemical approach.

Following Fröhlich's insights, we remark that in humans, as in other living beings, water accounts for about 70% of body weight and, in terms of molecular count, well over 90% of all molecules present. Yet, biochemical research primarily focuses on the few percent of other molecules, and regards the role of water as 'marginal' in the vital processes of biological systems.

Fröhlich also noted that living matter exhibits extraordinary dielectric properties. The electric potential difference across cell membranes, which have an average thickness of about 10^{-6} cm, is about 100 mV. The corresponding electric field is therefore about 10^5

V/cm—so intense that ordinary materials cannot sustain it (for example, silicon has a dielectric breakdown limit of about 0.4×10^5 V/cm).

It is worth noting that water can mediate electric interactions between aromatic ring structures in DNA and enzymes (Kurian *et al.* 2018), and, as experimentally observed, "a change in the state of hydration can lead to radical changes in DNA structure" (McDermott *et al.* 2017). Furthermore, recent studies (Wang, 2025) have shown that water exhibits high polarizability and conductivity when confined between plates separated by a distance of 2 nm. The resulting high dielectric constant, comparable to that of ferroelectrics, is attributed to strongly disordered hydrogen bonding induced by confinement to a few molecular layers. It was shown that water molecular dipoles in nanometer regions exhibit high polarizability, and that near-infrared spectroscopy measurements provide "a molecular indication for the discrimination of aberrant state of water structures from biologically functional one", leading "to achievement of non-invasive diagnosis of amyloidoses as a unique indicator of an early sign of aberrant aggregation state of protein molecules at latent symptomless stage" (Chatani *et al.* 2014). This suggests that the electric dipole of the water molecules may play indeed a role in biological systems.

In the next Section, we shall examine some aspects of QFT useful for the study of biological systems. We shall then proceed, in the subsequent sections, to illustrate the dynamical properties of water, CDs, microtubules, and so forth, following the outline presented at the end of Section 1.

3. QFT, Spontaneous Breakdown of Symmetry and Coherent States

Biological systems evolve through a succession of "phase transitions"; that is, they live by passing through different dynamical regimes, which differ at the microscopic level, while the macroscopic behavior of the system is governed by parameters whose variations can be described in classical terms (the order parameter fields).

The quantum formalism that accounts for the possibility of transitions between physically distinct dynamical regimes (phase transitions) is that of QFT. Indeed, in QFT infinitely many physically different dynamical regimes, or 'phases' exist, described by infinitely many state spaces, with their respective ground states (i.e., lowest energy or vacuum states), each one characterized by different physical properties (in technical terminology, infinitely many unitarily inequivalent representations of the quantum operator algebra) (Umezawa 1993; Blasone, Jizba, & Vitiello 2011).

It should be stressed that this is a crucial difference between QFT and QM (Umezawa 1993; Blasone, Jizba, &Vitiello 2011). The von Neumann's theorem (Von Neumann 1955; Itzykson & Zuber 1980; Bogoliubov & Shirkov 1983; Umezawa 1993; Blasone, Jizba, & Vitiello, 2011) in QM indeed states that all the representations of the quantum operator algebra are unitarily equivalent, i.e., physically equivalent. Therefore, in QM, all the vacuum (or ground) states are physically (unitarily) equivalent, which means that there is actually a unique vacuum state. The conclusion is that the quantum formalism one needs to describe biological matter is QFT, not QM (Del Giudice *et al.* 1983; 1985; Del Giudice, Doglia, & Milani 1986).

We also remark that living systems are dissipative (Vitiello 2001) and constantly coupled to the external environment. With "dissipative", we mean that they are *open* systems, i.e., in a permanent reciprocal exchange of energy, matter and information with the environment. Vital systems' isolation entails the elimination of their functionality and ultimately their destruction, which is lethal. Thus we need the dissipative QFT formalism (Celeghini, Rasetti, & Vitiello 1992; Vitiello 2001).

The quantum field equations, describing the dynamical evolution of the system, contain non-linear terms describing the interaction among the fields. Finding their solutions may be quite a hard task. It is then helpful to study, if any, the group of transformations of the fields with respect to a continuous parameter (e.g., an angle in the case of rotations), that leave the equations invariant (i.e., the form of the equations does not change when the fields are transformed). Then such a group of transformation is called the "symmetry group" for the equations, and thus for the dynamics they describe. On the other hand, the system may sit in one of the vacuum (lowest energy-) states (among the infinitely many unitarily inequivalent ones), which is not invariant under the symmetry group transformations. In such a case, one says that a "spontaneous breakdown of symmetry" occurs (Itzykson & Zuber 1980; Umezawa 1993; Blasone, Jizba, & Vitiello 2011). We remark

that spontaneous breakdown of symmetry occurs in the relativistic regime (in elementary particle physics) as well as in the non-relativistic regime (in many-body physics).

The experimentally widely tested Goldstone theorem holds in QFT. It states that when spontaneous breakdown of symmetry occurs, then gapless quanta are dynamically generated in the system (Itzykson & Zuber 1980; Umezawa 1993; Blasone, Jizba, & Vitiello 2011). These gapless quanta are called Nambu-Goldstone (NG) quanta, or field. Gapless means that the energy of these fields does not get contributions from mass terms. The wavelength associated to them (through the de Broglie relation) goes to infinity in the limit of zero momentum. This means that NG boson fields thus represent long-range correlations among the system elementary constituents. Their presence in the ground state is denoted by the term "condensation" and it is ruled by the Bose-Einstein statistics. When there is no negative interferences among the long-range correlations associated to NG, one says that these correlations are *coherent* ones, and there is '*coherent condensation*' in the ground state.

Well-known examples of NG boson quanta are the magnons in magnets, the phonons in crystals, and dipole wave quanta in dipolar systems. These behave just as quantum particles "within" the observed system. Therefore, they can be considered as (structural) effective elementary components of the system, describing its microscopic dynamics together with the other elementary components (Umezawa 1993; Vitiello 1998; Blasone, Jizba, & Vitiello 2011). Their presence can be detected by means of scattering techniques, yielding a corresponding spectrum (Del Giudice *et al.* 1988; Arani *et al.* 1995; Wolfe 1998; Del Giudice & Vitiello 2006; Giudice, Spinetti, & Tedeschi 2010; Bono *et al.* 2012); however, they are "confined" within the system, i.e., they do not propagate outside it.

An important remark about the coherent condensation of NG bosons in the ground state, is that their associated long-range correlations generate the ordering of the system's elementary components, specific of the case (geometric, magnetic, rotational, electric, etc.), and, consequently, the macroscopic structure of the system. Order's appearance is thus a result of the coherent condensation of NG bosons in the ground state, resulting in turn from spontaneous breakdown of symmetry. *Order is therefore lack of symmetry*.

The breaking of various types of symmetry generates a corresponding field, called the "order parameter" field (Del Giudice *et al.* 1983; Del Giudice, Doglia, & Milani 1986), which is thus of quantum origin, but, nevertheless, behaves as a classical field since quantum fluctuations are reduced at their minimal value in coherent states (Itzykson & Zuber 1980; Umezawa 1993; Blasone, Jizba, & Vitiello 2011). The order parameter provides a measure of the coherence (thus of the ordering,) and acts as bridge from the microscopic quantum dynamics to the macroscopic (classical) behavior of the system.

With relation to the notion of coherence, we stress that such a QFT coherence has nothing to do with the decoherence occurring in QM (Alfinito, Viglione, & Vitiello 2001). There, the word "coherence" refers to the constancy of the phase relation between the states in the superposition (wave functions) of a definite (not infinite) number of particles. Such a coherence is easily broken by environmental (noisy) effects. This defines the process of decoherence in QM. All this does not occur in QFT, as explained above.

In conclusion, any attempt to oppose QM decoherence processes requires energy to be pumped into the system (to keep it coherent) and energy to shield it from the noisy environment. This explains why QM coherence is so fragile and 'expensive'. On the contrary, QFT coherence, once triggered, even by a very weak stimulus, is very robust and may well survive in a hot, wet, noisy, and hostile environment.

As a familiar example, consider the magnetic needle of a compass. The needle's magnetization is the order parameter field describing the ordered state of the quantum components of the needle (the alignment of the elementary magnetic moments—dipoles—of the component particles, e.g., the electrons), and, at once, it is responsible for its classical behavior (its orientation) within the Earth's magnetic field. The symmetry that gets broken in this case is the rotational spherical symmetry of the elementary magnetic dipoles, and the NG quanta are the magnons (describing the long-range phase correlations among the elementary magnetic dipoles).

QFT formalism provides a unified perspective describing a variety of nontrivial phenomena through the dynamical relationship between the microscopic and macroscopic levels. Essentially, the bosonic

condensates enable a scale transformation (from the micro to the macro level), with macroscopic behavior, that is not "imposed" from the outside but is rooted in the quantum description of the microscopic components. Then, we can say that the system is a "macroscopic quantum system" (Vitiello 2001; 2024), since its macroscopic properties can only be understood in terms of the underlying quantum dynamics of its elementary constituents. As already noted, such descriptive power is not achievable within QM, which admits only a single ground state (and thus no phase transitions) (Von Neumann 1955; Blasone, Jizba, & Vitiello 2011). Moreover, we stress that our qualitative discussion, offers, step by step, a detailed rigorous mathematical realization in the QFT formalism. The interested reader may find all formal details in the quoted literature.

In conclusion, considering the study of a biological system and its time evolution through different dynamical regimes, we see that we necessitate admitting the existence of a variety of vacuum levels, i.e., phases (describing those different dynamical regimes). In other words, living matter continuously transforms and reorganizes itself to maintain the energy of the adopted configuration at a minimum at any given moment, in response to constant exchanges with its surrounding energy fields. Any living being can be viewed in these terms. We must therefore move from the study of a biological "state" to the study of the biological system of relationships among fields. This is made possible by QFT, in which phase transitions and symmetry breaking can be described dynamically. Breaking of continuous symmetry is in conclusion a prerequisite for the emergence of ordered 'pathways' in biological systems (biochemical reactions and the compartmentalization of functional domains) that strive to maintain vital homeostasis.

4. Dipole Wave Quanta and CDs

In biological systems, electrical dipoles characterize the majority of present molecules, biological macromolecules and water. These last ones are by themselves, as said in Section 2, more than the 90% of all the present molecules. Relevant degrees of freedom are therefore associated with the molecular electrical dipole rotations (dipole orientations). The SU(2) group of continuous rotation transformations enters thus as a symmetry group for the dipole field equations. The presence of ions, electron currents, and other electric perturbations triggers the breakdown of the SU(2) continuous symmetry with the dynamical generations of long-range phase correlations among the dipoles (the Goldstone theorem, cf. Section 3). The associated NG quanta are called dipole wave quanta. The lowest energy state (the ground state or vacuum) of the biological system is thus a coherent dipole wave quanta condensate. The order parameter field is the polarization field density P(x,t), expected to be non-homogeneous in space and in time due to the non-homogeneous molecular, cellular and structural composition of the system.

We thus see that the study of biological systems may develop on two connected levels. The first level is the microscopic quantum one, with time evolution equations describing electric dipoles rearrangements and fluctuations, electronic charge clouds, and other quantum components of the system. The second one is the macroscopic 'classical level' whose evolution in time and rearrangement in space (e.g, compartimentations, cellular and tissue formation, morphological and physiological phenomena) are controlled by equations for the polarization density P(x,t), and other classical parameters and fields, commonly studied in classical biology—mostly conditioned by, or dependent on the order parameter P(x,t). The common, traditional biochemical approach thus finds its own validity, even without "immediate" recourse to the underlying quantum dynamics, although it actually sustains it.

The mathematical analysis shows that surface boundaries, space-time dependent densities, ions, free charges, electronic currents and the associated EM field, interacting with the water molecular electric dipoles, may confine the coherent condensation regions within water domains of finite size, denoted CDs. The EM field remains trapped, in a phase-locking process, within the coherent region.

The size of the CD relates to the frequency of oscillation of the liquid water molecule, in resonance with the trapped EM field, between its ground state and its first excited state. It occurs at 12.06 eV, for density and specific heat at ordinary conditions. Typical size of a CD diameter at ambient temperature is about 80 nm (Bono *et al.* 2012; Renati & Madl 2024; De Ninno & Gamberale 2025), see Fig. 2. Considering that in the non-coherent state, the ionization potential, with release of one electron, is at 12.62 eV, we see that for the

molecules in the coherent domain at their first excited level, the energy need for a ionization electron is quite low (0.55eV). This means that under such conditions, CDs can easily be sources of quasi-free (ionization) electrons; a very convenient scenario for biochemical activity, electrons being the 'exchange currency' promoting chemical interactions.

The scheme qualitatively described above, finds its mathematical formulation, among others, in (Del Giudice *et al.* 1983; 1985; Del Giudice, Doglia, & Milani 1986; Blasone, Jizba, & Vitiello 2011; Dal Lin, Romano, Iliceto, Tona, & Vitiello 2022), and it is supported by several experimentally observed phenomena. See, e.g. (De Ninno & De Francesco 2018) where spectral observations show the two-fluid (coherent and non-coherent) composition of water, also showing spectral evidence of molecular water structures, and (De Ninno & Gamberale 2025) where many commonly observed water's 'anomalies' are explained. It also accounts for the frequent high confidence and efficiency of biochemical pharmacological tools, whose expectation to be successful solely based on the intrinsic randomness

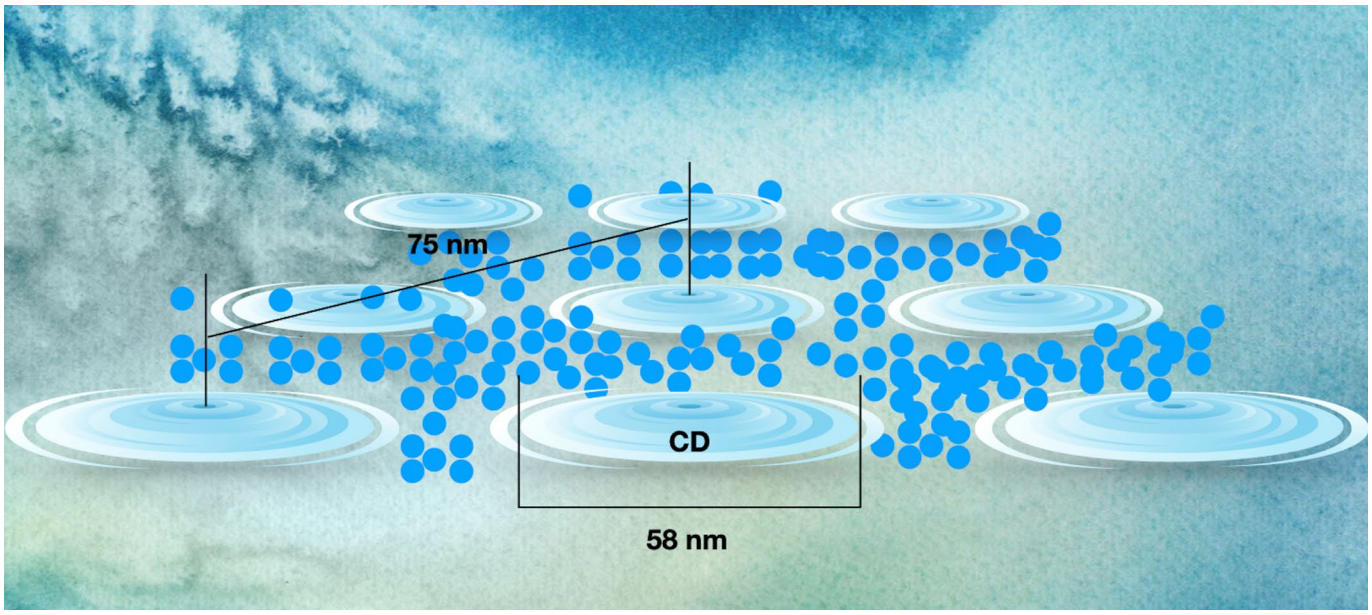

Figure 2. An artist's sketch illustrates the biphasic nature of liquid water: at room conditions, the coherent fraction, Fc(T), comprises about 40% of the total molecules, and its density (0.92 g/cm^3) is independent of temperature, whereas the density of the incoherent (interstitial) fraction depends on Temperature. The thermal stability of coherence domains at room temperature is based on the existence of an energy gap generated by the collective, synchronized interaction between matter and the EM field. According to the quantum electrodynamics (QED) coherence theory, CDs are spatial regions where molecules (such as water molecules) oscillate in unison, in phase with an EM field trapped inside the domain itself. The reason why ambient thermal agitation at room temperature (about 20-25 °C or 293 K) does not destroy these macroscopic structures lies in the following key factors.
i) The energy gap—the transition from a disordered (incoherent) state to a coherent state is a thermodynamic phase transition that lowers the overall energy of the system. The difference in energy between the more stable coherent state and the incoherent state constitutes the energy gap.
ii) Barrier against fluctuations—at ordinary temperatures, the average collision energy linked to thermal fluctuations (kBT), where (kB) is the Boltzmann constant, is lower than the magnitude of the energy gap. Consequently, ambient heat does not possess enough energy to break the synchronized configuration of the molecules inside the domain.
iii) The role of density and collective mass—because this phenomenon involves a massive number of molecules behaving as a single macroscopic wavefunction, the system's inertia against random thermal noise is extremely high. Thermal agitation acts at the microscopic level on individual molecules but cannot easily decohere a collective, macroscopic coherent cluster. Thus, at ordinary temperatures, matter (such as liquid water) behaves as a two-fraction system. Its coherent fraction is made of stable CDs, which maintain their geometric and dynamic structure thanks to the energy gap. The incoherent fraction includes free molecules filling the spaces between domains. These molecules absorb the main impact of thermal agitation and move in a purely random manner (Brownian motion). As temperature increases, the incoherent fraction grows at the expense of the coherent one. If a specific critical temperature is exceeded (where the thermal energy (kBT) equals and surpasses the energy gap), then the coherence domains finally collapse, turning the system into a completely incoherent state (e.g., the transition to the vapor state) (Caligiuri 2022).

of chemical reactions would be, otherwise, very poor. Let us recall Schrödinger's warning (Schrödinger 1967 [1944]) that "regularity only in the average", of statistical nature, is not sufficient to explain the "enigmatic biological stability" (cf. Section 1).

5. CDs and their dynamics

Let us now examine how multiple CDs may interact with one another and how they may relate to an electrically charged surface, as in the case of an ordinary cell membrane. From this, we obtain a view of what might occur in the cellular cytosol or within blood vessels (bearing in mind the "practical" explanatory purpose of this theoretical discussion: in our aforementioned studies, we collected blood samples). From our discussion, relevant insights emerge for understanding the spatial distribution of solutes, their changes, and the directionality of chemical reactions within cells.

As mentioned in Section 4, spectral analysis of liquid water in specific conditions (e.g., in strong electrolyte solutions) shows that it is a two-component fluid (De Ninno & De Francesco 2018), namely, it comprises a fraction of molecules organized into CDs and a "free" fraction of sparsely distributed molecules. Moreover, we have mentioned that CDs can be sources of quasi-free (ionization) electrons, noticing that this provides a very convenient scenario for biochemical activity (electrons are the 'currency' promoting chemical reactions).

These electrons generates orbital motions on the surface of the CD, referred to as "cold" vortices because, owing to their non-trivial topology they cannot undergo thermal relaxation (conservation of the winding number). As for the electrons, an analogous reasoning applies to proton oscillations (Ho 2008). Within the CD, electronic charges associated with the various possible excitation levels may find a superconductive state (Del Giudice *et al.* 1988; Del Giudice & Vitiello 2006). Moreover, different synchronization patterns can be established among water molecules, even those belonging to different coherence domains, thereby forming CDs over extended regions. The energy absorbed by the system cannot be released as heat, but only as work or enthalpy, provided that a suitable partner is available. This principle gives rise to supercoherence (Del Giudice *et al.* 2005): multiple coherence domains cooperate in an ordered manner to maintain overall coherence. Supercoherence, so defined, enables ordered and efficient energy flows, prevents thermal dissipation, and ensures functional stability.

For coherent system, the oscillation phase is well defined. At the quantum level, there exists the uncertainty relation, $\Delta\theta \times \Delta N \geq 1/2$, between the phase θ and the number of oscillators N. This holds across

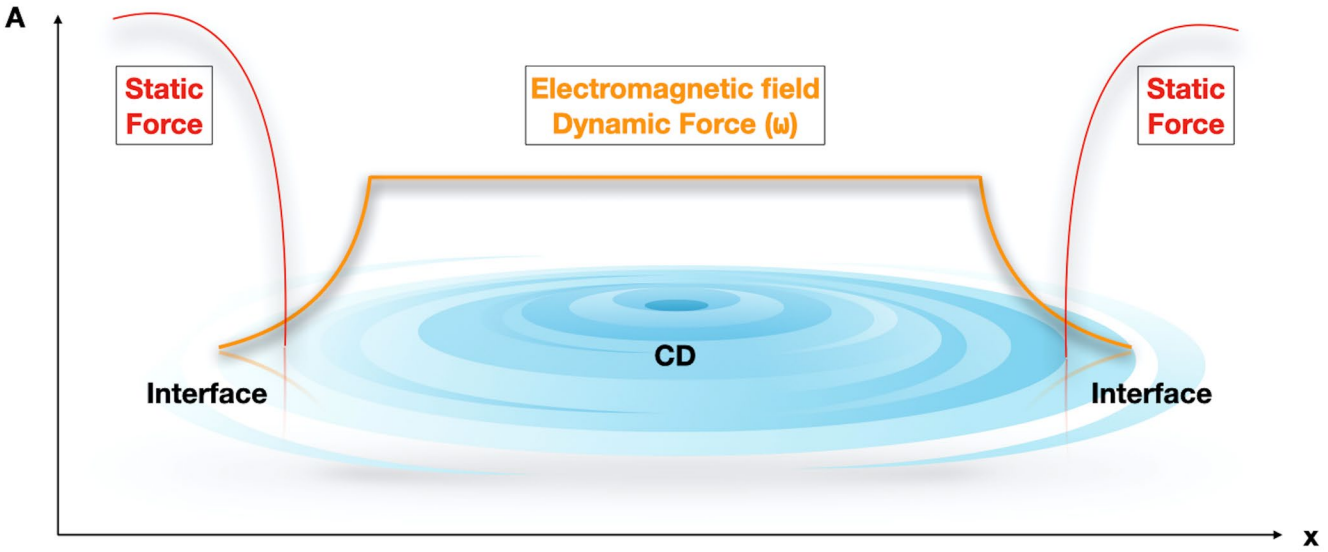

Figure 3. A coherence domain (CD) can be described as a system in which a self-confined EM field decays exponentially from the interior toward the exterior, generating a static ponderomotive force and a dynamic force based on the oscillation frequency of the EM field (ω).

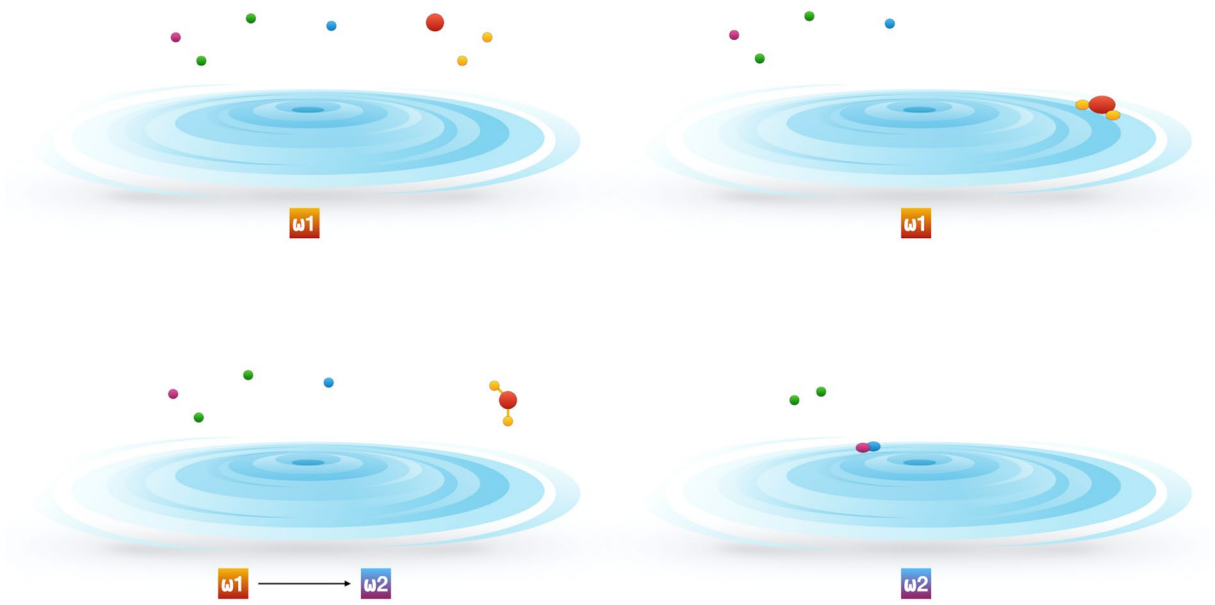

Figure 4. Water, with its electrons close to the ionization threshold, recruits at the CD boundary those molecular species whose oscillation frequencies are resonant with that of the field (top right), subjects them to a "mass-mover" force that destabilizes them, and promotes their chemical reaction by donating electrons. This process entails a change in the working frequency of the CD's EM field (bottom left), which in turn recruits other molecular species at the CD periphery (bottom right). These will again be subjected to the "mass-mover" force and will thus be guided to interact with one another in an orderly manner. In this way, a chain of reactions can arise within a cellular system.

multiple scales (Del Giudice *et al.* 2011), and may be extended also to the classical level: among molecules that constitute compartments of biochemical reactions; among cells that form tissues; among tissues that form organs and systems; among systems that form organisms; and among organisms that form ecosystems. Living systems that maintain homeostasis must share their oscillations with a large number of other systems.

Within the QFT framework, the CD (cf. Section 5) can be described as a system in which a self-confined EM field decays exponentially from the interior towards the exterior, thereby generating a pronounced intensity gradient (Del Giudice *et al.* 2011). This configuration gives rise primarily to two types of forces (see Fig. 3): 1. Static "mass-mover" force (red lines), independent of the oscillation frequency, deriving from the gradient of the square of the EM field. They manifests as a pressure that tends to expel electric charges from the domain itself. The magnitude of the force is inversely proportional to the mass of the charge involved, and is therefore particularly relevant for light particles such as electrons.

Selective dynamic frequency-dependent force (yellow lines): exerted on the system's constituents, it is a function of the collective oscillation frequency ω and promotes long-range attraction among those molecular species whose resonance frequencies are compatible or closely matched. In an environment containing a multiplicity of species, only those whose oscillatory modes are in resonance with those of the domain are selectively attracted, thereby fostering specificity and order in aggregation processes and in physico-chemical reactions.

Consequently, the coherence domain effectively acts as a natural selector, not only based on physical proximity but, crucially, on the tuning between the characteristic frequencies of the present collective oscillators.

In a biological context, the fraction of free water contains numerous ions and molecules (oxygen, sodium, carbonate, amino acids, etc.). Each of these components, with its own EM oscillatory characteristics, is selected by the electrodynamic force, and its electron cloud is destabilized—"stretched"—by the static force within the water coherence domains (Del Giudice *et al.* 2011). Only particular solutes or molecules whose oscillation frequencies match those of the CD will be attracted to its boundary. This system allows redox processes to occur with high efficiency and precision, easily overcoming the energy barriers that would normally hinder such reactions.

Dynamically, the domain oscillates, attracting molecular species predisposed to react. Subjected simultaneously to the static and dynamic components of

the field, these species are ready to exchange electrons. Water, thanks to the quasi-ionized electrons present in the coherence domains, can donate electrons at very low energy (0.5–0.20 eV) (Arani *et al.* 1995; Preparata 1995; Bono *et al.* 2012; De Ninno & Gamberale 2025). When these electrons are transferred to the reacting species attracted to the CD boundary, thus enabling their combination reaction, the coherence domain changes its frequency, recruiting additional molecules and facilitating the continuation of further responses. This gives rise to an ordered sequence of reactions, typical of cellular systems (Fig. 4).

This mechanism generates a specific spatial arrangement in which specific biochemical reactions can take place. A cellular system can, in fact, be viewed as a hierarchy of super-domains of water domains, where the interfaces among the various domains organize surfaces that enable all cellular water to remain coherent, thereby supporting vital processes (Voeikov & Del Giudice 2009).

6. The Excusion Zone

In Figure 5, we see that there exists a proximal region adjacent to a hydrophilic (negatively charged) surface toward which water exposes negative charges (Pollack 2014). If electronegative surface groups oscillate at frequencies similar to those that water can sustain as an H_2O complex, an attractive force develops, and over long distances an interaction arises that draws in negative charges (Voeikov & Del Giudice 2009; Cifra, Fields, & Farhadi 2011; Yinnon *et al.* 2016).

As Feynman famously stated (Feynman 1970), "like likes like": like attracts like. Except at short range, where Coulomb (electrostatic) repulsion prevails, in more extended ranges the electrodynamic force dominates. By resonance, "external" negative charges, associated with the ponderomotive force of the water coherence domains are themselves attracted and packed near the surface, thereby exposing a fraction of positive charges (H^+) (this is the source of oxidation, particularly when the brain sends signals that diverge from those of the heart, given that membranes are negatively charged surfaces). In the presence of a hydrophilic surface with a predominance of positive charges, the opposite arrangement of ionic species is obtained (Pollack, 2014). The configuration with the less exposed negative charges is more powerful, because the "mass-mover" force is more potent and because electrons have more possible configurational modes than protons (which is why this configuration is more frequently found in nature). The volume occupied by the coherent fraction of water is greater when the membrane surface charge is negative (Renati 2021). In such cases, surfaces bearing a nonzero charge density can resonate with the rotational motions of water.

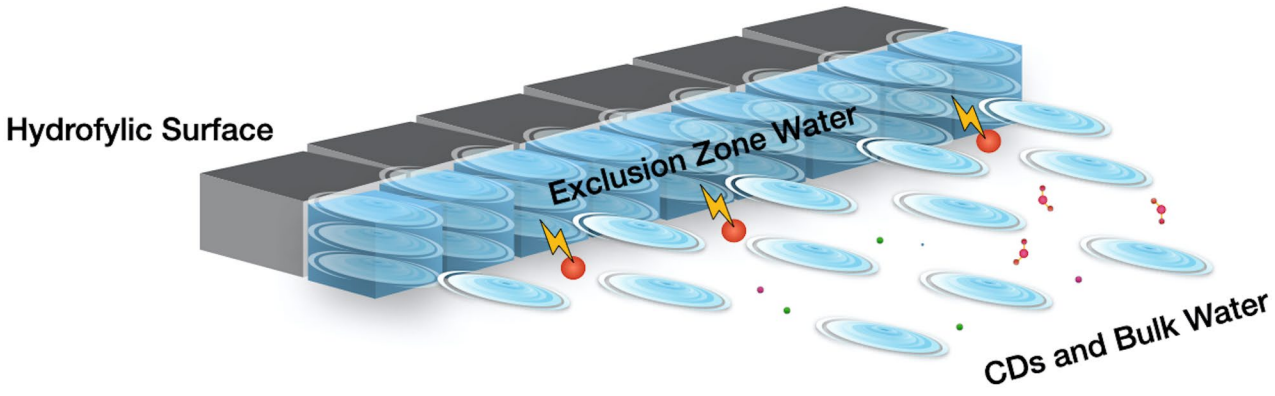

Figure 5. Water organisation near a hydrophilic surface—explanation in the text.

Facing an electrically charged surface, an additional degree of freedom becomes relevant for the establishment of coherence: no longer only the oscillation of electrons in the water molecule, but also the rotation of molecular dipoles (with lower oscillation frequencies, longer wavelengths, typically in the microwave range) (Debenedetti & Stanley 2003). Upon adhering to the surface (and thereby losing rotational invariance in space), water organizes into a very thick layer (orders of magnitude larger than estimates based solely on electrostatic interactions), extending up to hundreds of micrometres, into which no solute can enter (with the sole exception of the proton, H^+, because of its tiny size). This layer is termed the "exclusion zone" (EZ).

EZ water displays many properties that, in a dynamic sense, make it akin to a "fourth phase of water" (Zheng *et al.* 2006; Pollack 2014; Karbowski, Murugan, & Persinger 2016). That is, it constitutes a system whose kinetics are markedly different (slower), not for energetic reasons but, one might say, for inertial ones, as in glasses. It may thus be meaningful to speak of a "glassy state" of water (Debenedetti & Stanley 2003). As described by Pollack (Zheng & Pollack 2003; Zheng *et al.* 2006; Pollack 2014), the EZ carries a negative electrical potential of up to –150 mV relative to bulk water; at the interface between EZ and bulk water, H^+ ions accumulate; EZ water exhibits an absorption peak in the UV at 270 nm and emits fluorescence when excited at this

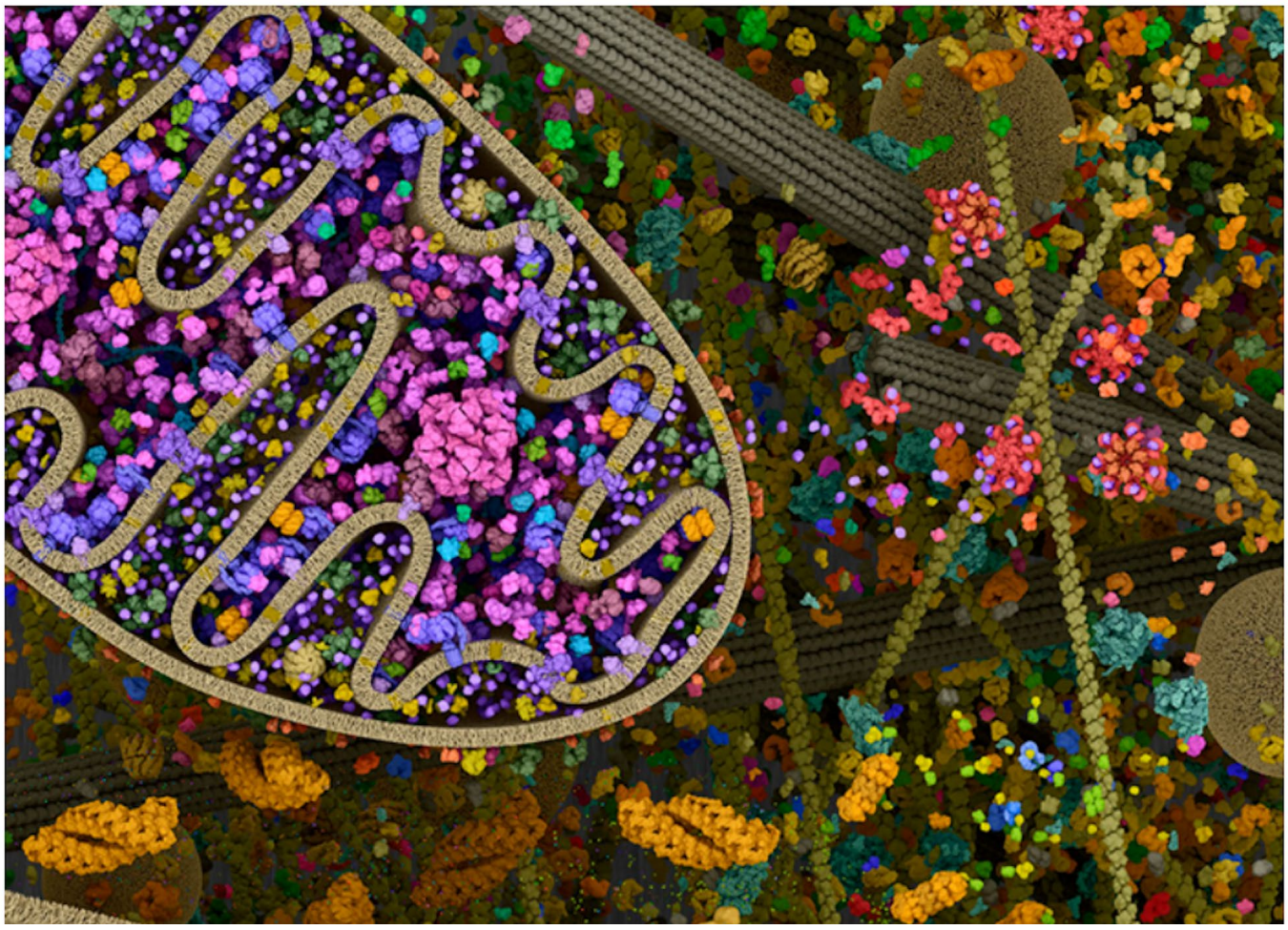

Figure 6. A section of the cytoskeleton of a eukaryotic cell (a scanning electron microscope (SEM)). A cross-section of a mitochondrion is visible, along with actin fibers (in olive green) and microtubules (in grey). The short yellow–orange spirals represent tripeptidyl peptidase 2. A striking feature is the highly compartmentalized topology: no free space larger than a few micrometres is interposed between neighboring molecular structures. It should be kept in mind that SEM image is an artefactual portrait of the sample, since it must be dehydrated (because it is analyzed in a vacuum). Thus, all the apparent interstices should be imagined as occupied in vivo by the super-coherent water matrix, which is the proper structural medium of the system. [Image source: https://media.cellsignal.com/www/html/science/landscapes/mitochondria/mitochondria.html].

wavelength; weak infrared irradiation increases the thickness of the EZ to almost millimetric dimensions by bringing nearby molecules of the incoherent phase into resonance, thereby facilitating their coupling; the EZ–bulk water pair behaves as an electrochemical cell, and their interface constitutes a vast source of electrons that can be easily donated to sustain redox reactions (Renati, 2021). It bears repeating that we are dealing with coherence domains structured on the degrees of freedom associated with electronic excitations and dipole rotations of water, with characteristic dimensions of hundreds of micrometres (Zheng *et al.* 2006; Pollack 2014; Karbowski, Murugan, & Persinger 2016).

Electrons can leave EZ water (EZW) via tunnelling to suitable acceptor species present in the system; typically, given its electronegativity of about 0.44 eV, the preferred acceptor is the oxygen molecule (O_2) (Voeikov & Del Giudice 2009). In the presence of other solutes, such as simple gas molecules (nitrogen, carbon dioxide), chemical reactions can occur that generate progressively more complex molecular species (carbonyls and amines), eventually giving rise to polymeric and membranous (hydrophilic) systems that form new surfaces on which fresh vicinal water (EZW) can spontaneously organize, and so on (Voeikov & Del Giudice 2009). Moreover, the phase-locked electron clouds in such a complex system—electronegative surface–water–EZW–solutes—generate superconductive currents, themselves synchronized (Del Giudice *et al.* 1988; Arani *et al.* 1995; Preparata 1995; Bono *et al.* 2012; De Ninno & Gamberale 2025) within the corresponding EM field. The interplay of attractive and repulsive forces can thus create regions of potential difference, as well as deformations and interpenetrations of fields that organize polymeric structures in space (linear, vesicular, spherical, etc.).

In this way, field potentials localize molecules and likely constitute the prerequisite for the emergence of membranes and mono-, bi, and three-dimensional structures.

From this perspective, the cellular images to which we are accustomed (Fig. 6) may be regarded as casts, or negative transparencies, of the structural organisation of different, mutually interacting water coherence domains.

7. Tissues, Structures and Energy Transfers

Up to this point, we have outlined the biophysical background that can account for the rapid, orderly, and simultaneous multiparametric changes in the concentration of various biochemical mediators, in the spatial conformation of von Willebrand factor polymers, in the reduction of oxidative phenomena, and in the alterations of plasma electrical properties observed in our studies. But what about larger scales of organization? What can drive an orderly change in cardiac volume, or a reduction in the contractile capacity of the heart, and how do multiple myocytes coordinate to yield an integrated response such that the same amount of work is performed—i.e., 5 L/min of blood is pumped—but with fewer beats during RR practice? What underlies telomere lengthening in the white blood cells we analyzed? How is gene expression modulated? Or how does a carotid plaque exhibit even a slight reduction in thickness? These questions move us to a more macroscopic scale than that addressed thus far.

We therefore broaden our perspective: from the "local" interactions among CDs, between CDs and ions or solutes, and between CDs and electrically charged surfaces (membranes), we turn to mechanisms that might govern the relationships among distinct compartments–modules structured in the same way (water CDs and membranes). This can provide insights into the functioning of different cellular districts, and into how multiple cells aggregate into tissues, organs, and so forth.

Different clusters of molecules form structures and chains of biochemical reactions that occur with specific timing and in precise spatial locations, and these may represent "confinements" of matter at the interfaces of field potentials generated by water CDs. Electrostatic (Coulomb) interactions are also present between these clusters.

In living systems, there is an inseparable link between two levels: (1) the EM level, which localizes, organizes, and times events, and (2) the biochemical level. In coherent systems, the proper biological functioning can be discerned. Returning to the earlier figure (CD recruiting ionic species and inducing their reactions…), the composition of a system depends on the temporal variation of its oscillation frequencies: this leads to a

notion of order far more sophisticated than that of simple inorganic crystals. It is an order of motion, of change, not merely of spatial regularity. It is the kind of order that, as Schrödinger emphasized, does not imply uniformity, when he compared biological molecules to "aperiodic crystals".

From a physical point of view, a tissue is a coherent ensemble of cells, which in turn are composed of field niches containing quanta of matter that perform work (organelles delimited by membranes, located at the interface between two sets of molecules and solutes across which a change in oscillatory phase occurs), and subcompartments characterized by different oscillation regimes (Ho 2008; Ho n.d.).

Coherence not only structures the pathways of biochemical reactions but also helps define the topologies and boundaries of domains, which are privileged regions for the accumulation of matter (e.g., molecules and ions). Space is organized by the oscillation (working) frequencies of water CDs. Within these confined compartments, dynamics arise that are characterized by specific spatiotemporal (vibrational) scales. A paradigmatic example is provided by proteins, which can adopt up to 10^6 steric configurations per second, exhibiting remarkable conformational plasticity (Acbas *et al.* 2014). Enzymes, on the other hand, catalyze reactions on the order of 10^3 processes per second (Boyle 2008). The conformational reconfiguration of the enzyme thus occurs at a frequency roughly one thousand times higher than that of its catalytic events. For the substrate, this implies that the enzyme's conformational fluctuations are perceived as static, since the timescale of catalysis is significantly slower than that of the protein's internal motions (Ho 2008; Al-Khalili & McFadden 2014).

The presence of coherence explains how the entropy of the system can be minimized: ordered, synchronized oscillations that generate entropy on a smaller scale correspond to energy that can be stored and used to produce work and order at a subsequent, larger scale. The compartmentalization of work cycles, mediated by field-matter-quantum interactions across successive vibrational scales, allows energy to be channeled efficiently and ensures order in vital processes (Fig. 7) (Ho 2008).

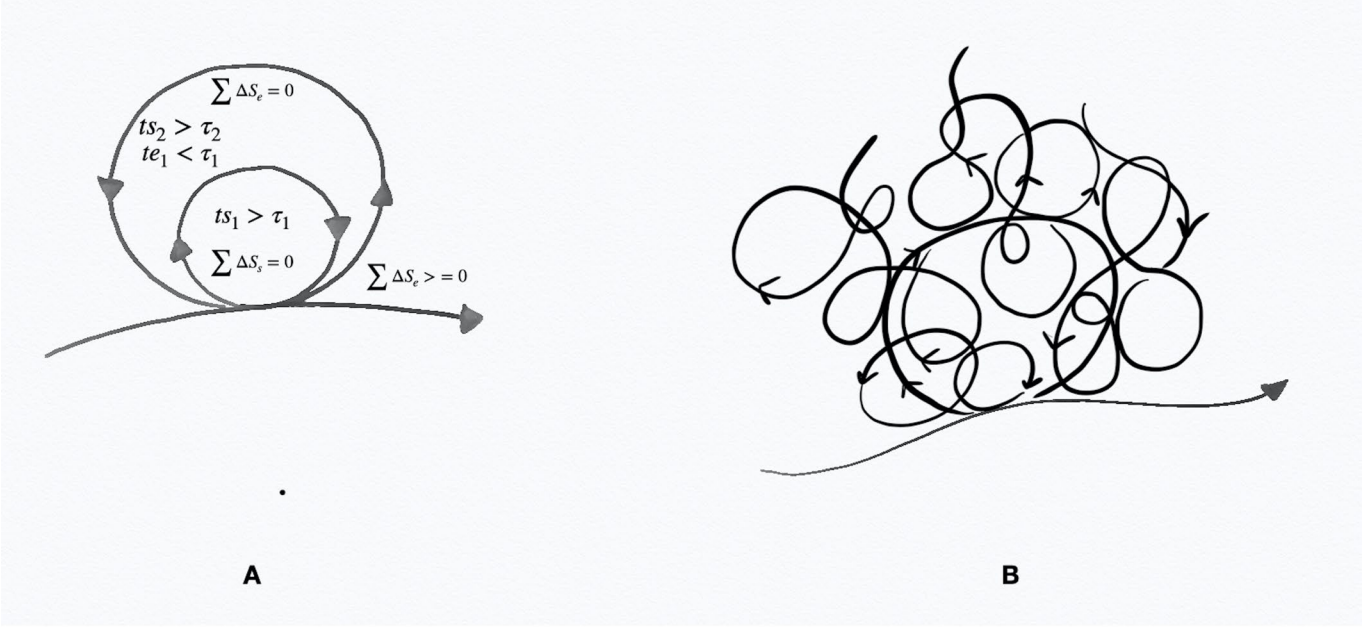

Figure 7. Picture drawn based on the schemes present in (Ho 2008). A) Schematic representation of two levels of coupled flows in a nested system (such as an organism or an ecological network), in which the energy flow through the whole system generates cycles at different space-time scales, each characterized by its own typical timescale, τ. This organization allows thermalized energy (locally equilibrated at a given level) to be transferred and used as stored, usable energy at the next larger, slower scale. B) Sketch representing the manifold of coupled cycles of life associated with and embedded in an energy flow in an organism.

About energy transfer, a coherent system can distribute energy in two main ways: as free energy, conveyed, for example, by a resonant photon (see below), or via slower thermal processes, in which energy is dissipated as heat with a corresponding increase in entropy. An analogy with a combustion engine is illustrative: during the expansion of a gas confined within the combustion chamber, the disordered agitation of gas molecules (increase in entropy) does not necessarily represent a loss of energy, since, in the context of a confined-compartmentalized system, this energy can be converted into mechanical work (movement of the piston), thereby remaining available and usable.

Indeed, if the characteristic timescale of a given level of coherence is τ_1, anything that thermalizes on timescales shorter than τ_1 would produce entropy at that level. However, at the next higher level, what is "ultrafast" for the first becomes "slow" because the re-equilibration time is longer. Thus, what for the subsystem appears as thermal energy and disorder, for the next-level system constitutes order and work (Ho, 2008). Compartmentalization is therefore the *conditio sine qua non* for the existence of order in living systems. Moreover, the interlocking of energy flows and field potentials organizes matter in space; just think of the convective topologies generated by a thermal gradient that give rise to cellular patterns (Fig. 8) (Beloussov 2012).

Energy transfer can also occur via direct passage under resonance conditions. Oscillatory systems exhibit different yet coordinated working frequencies, like a jazz band in which various instruments play different notes while maintaining a precise rhythmic pattern (Ho 2008; Ho n.d.). By varying the resonance condition between two interacting systems, one can mediate direct energy transfer because, under such conditions, partial or total periodic wave superpositions occur. This mechanism appears to rely on transitions between rational and golden (irrational) ratios (Renati 2021). The golden ratio is an irrational number, not expressible by a finite ratio; thus, given two oscillation frequencies of two structures with ratio r, their independence and energetic separation can be maintained if r takes irrational values. Energy can instead be transferred through resonance if r is rational.

The distribution of rational and irrational numbers on the real line is finely interspersed (Panchelyuga & Panchelyuga 2012); this means that a system composed of oscillators can, in principle, switch between resonant and non-resonant conditions with only minimal change. It is precisely this tuning that water is capable of achieving (in view of the many electronic excitation levels it can access once excited by the incoming photon,

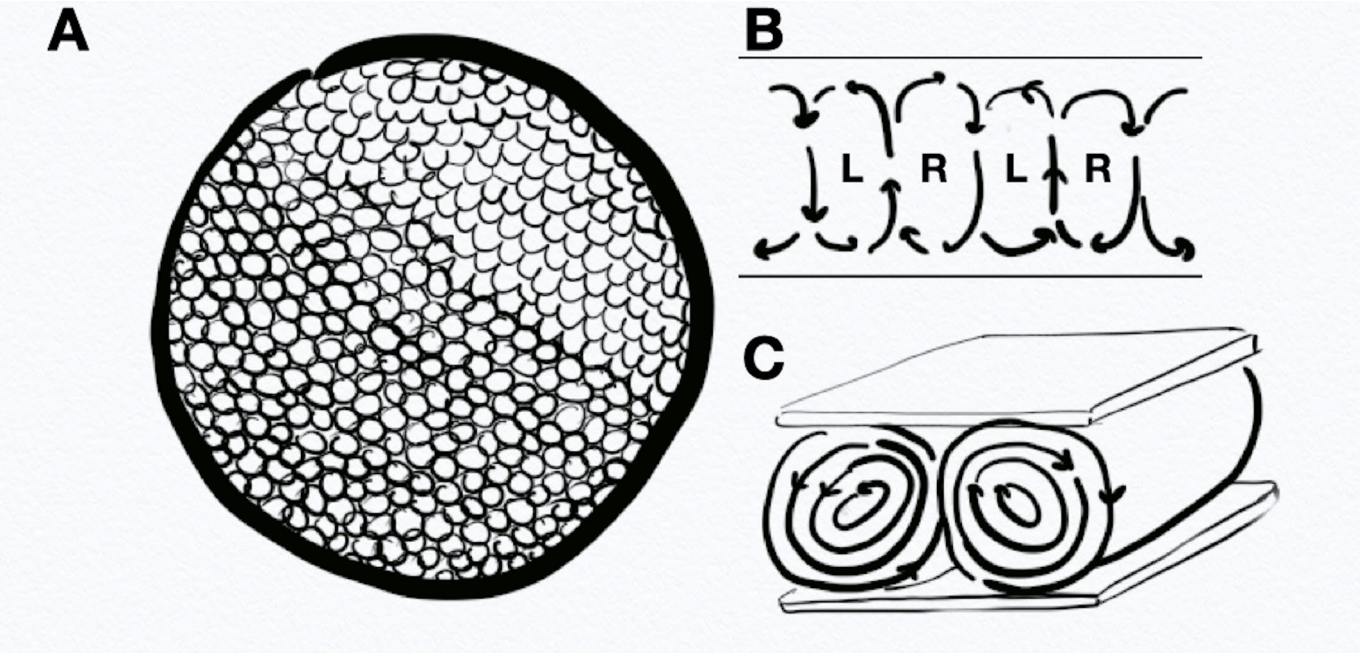

Figure 8. Picture drawn based on the schemes present in (Ho 2008). A Benard cell. A: general view from the top. B, C: schemes of coherent convection streams.

etc.), thereby allowing, through its mediation. These phase couplings among different reactants may be even quite "distant" from one another.

If r is an irrational number, no resonance condition is possible, since the two regions of the system have "incommensurable" frequencies, with dissonant, distinct rhythms that never coincide. Their phase space is described by quasi-periodic orbits (so-called KAM tori). Under such conditions, no coupling with consequent transfer of free (non-thermal) energy can occur. Only stochastic diffusion (where permitted by the energy gap) and exchange of thermalized energy are possible.

In light of our work, cardiac behavior may become more efficient through coherent dynamics that optimize couplings and energy exchanges among the molecules and cells involved in cardiac contraction. Since the heart is a structure formed by contractile components, and given that cellular contraction depends on a directed and sequential "attachment-detachment" mechanism between cytoskeletal molecules—actin and myosin—we now turn to some biophysical aspects of this topic, using as an example the best-studied cytoskeletal elements for which the most detailed biophysical information is available: microtubules. We believe that the following considerations can be naturally extended to the actin-myosin system as well.

8. Self-focusing of the EM Field, Cytoskeleton and Microtubule

In many-body physics, it is known that an electromagnetic (EM) field is expelled from a coherent system by the Meissner effect (Feynman 1970; Umezawa 1993; Blasone, Jizba, & Vitiello 2011), provided its intensity is below a threshold depending on the degree of coherence of the medium. However, if the field intensity is sufficiently high, the field may propagate in the medium by self-focusing, i.e., by destroying the coherence within a channel through which it propagates in a filamentary fashion. For higher intensities, the field may propagate in spherical waves by destroying the medium coherence (Del Giudice, Doglia, & Milani 1986; Del Giudice *et al.* 1988; Del Giudice *et al.* 1989). The observed self-focusing diameter of an optical light beam in simple liquids is of the order of a micron. The optical Kerr effect expresses the variation of the refraction index of the medium in terms of the propagating EM field (Shen 1975; Del Giudice, Doglia, & Milani 1986).

It has been shown (Del Giudice, Doglia, & Milani 1986) that in coherently fully polarized water, the self-focusing threshold energy is 13.60 eV, depending on the water molecular polarization P(x,t), on the water molecular electric dipole, and on the electron mass and charge. The diameter of the tubular 'channel' is computed to be 147 Å, in excellent agreement with the observed diameter of a microtubule in cytoskeletal structures (tubulin microtubules, kinesin, actin, myosin, etc.) (Cifra, Fields, & Farhadi 2011). Notably, no other quantitative analysis in biology can currently predict the internal diameter of microtubules (Del Giudice, Doglia, & Milani 1986).

The EM field confined within the filament produces field gradients at its boundaries (outside the filament there is no EM field), giving rise to attractive or repulsive forces that attract or repel molecules able to resonate with the EM field, thereby creating a local enrichment of reactants along microtubules, collagen fibers, hyaluronic polymers, and actin.

This might also explain the process of coating of the filament by tubulin molecules. Microtubules are indeed composed of two different conformational types of tubulin, alpha and beta, which allow them to interlock in a helical arrangement. The electric potential generated by the tubulin longitudinal pulsations induces an asymmetric and saw tooth-like motion (Astumian 1997; Cifra, Fields, & Farhadi 2011) (cf. Fig. 9) on a charge moving along the tubulin chain. A "ratchet" mechanism is thus established—a stepwise, rack-and-pawl dynamics. An electric charge migrates into the lowest potential region; however, if this potential is subjected to periodic fluctuations (it is "shaken" by the oscillation of tubulin monomers), then the probability that the charge will access the adjacent potential well becomes asymmetric. It acquires a preferred direction dependent on tubulin oscillations (Astumian 1997). Along the sequence of alpha-beta tubulins, a kinesin molecule, which carries a net electrostatic charge and is therefore bound to the cytoskeletal structure, moves in a preferred direction, that can change as a function of the microtubule's oscillation frequency (mechanotransduction stimuli) and also as a function of the oscillation patterns of the surrounding coherent water.

Filamentous structures such as proteins, hyaluronic polymers, collagen fibers, and proteoglycans (which

pervade connective tissue over long distances) are also relevant since they are wrapped (hydrated) by coherent water domains with a cross-sectional thickness of about 20–30 Å (Clegg 1982; 1984). These domains coat the filaments, adapting to them and forming sleeves, losing their spherical shape, and taking on a hollow cylindrical shape known as "bound water" or "structured water" (Fig. 9).

An increasing number of studies demonstrate the hydration of different molecular species and cellular structures (Mallamace 2010). Bound water thus forms a protective sleeve of defined chirality (Fogarty & Laage 2014; Duboué-Dijon *et al.* 2016; McDermott *et al.* 2017). Remarkably, the architecture of water molecules persists even in the absence of the biochemical elements with which they interacted; this has been observed, for example, in studies on DNA molecules (Montagnier *et al.* 2010; Meijer & Geesink 2016; Perets & Yan 2017; Ventura 2017; Kurian *et al.* 2018).

The corresponding coherence domain has a spatial scale determined by the wavelength of the trapped field, and, consequently, junctions ("gap junctions") arise in the regions where the various coherence domains nearly touch one another, forming sleeves. Solutes can access these sites, and chemical reactions can occur there (Renati 2021).

Around the sleeve, moreover, currents may arise along ordered paths (which would instead be random in a spherical domain), implying the formation of a magnetic flux along the sleeve. In the case of a closed path, electrons moving along them give rise to current loops whose intensity (given an essentially constant charge) depends on the rotation frequency of the electrons.

This means that the output of chemical energy, arising, e.g., from a reaction at the gap junctions, may be converted into quantized magnetic flux confined within the bound-water sleeves surrounding the protein backbone, and vice versa.

The quantization of magnetic fields at the microtubular level (of the order of 0.5–2.5 GHz) (Del Giudice *et al.* 1989; Vitiello 2010) has two significant consequences: (1) the possibility of non-resistive, Josephson-like supercurrents in tubular CDs and along their junctions (due to energy transfer from a local chemical reaction, the magnetic field of the hollow cylinder of coherent water surrounding the protein chain is excited, which in turn induces a Josephson

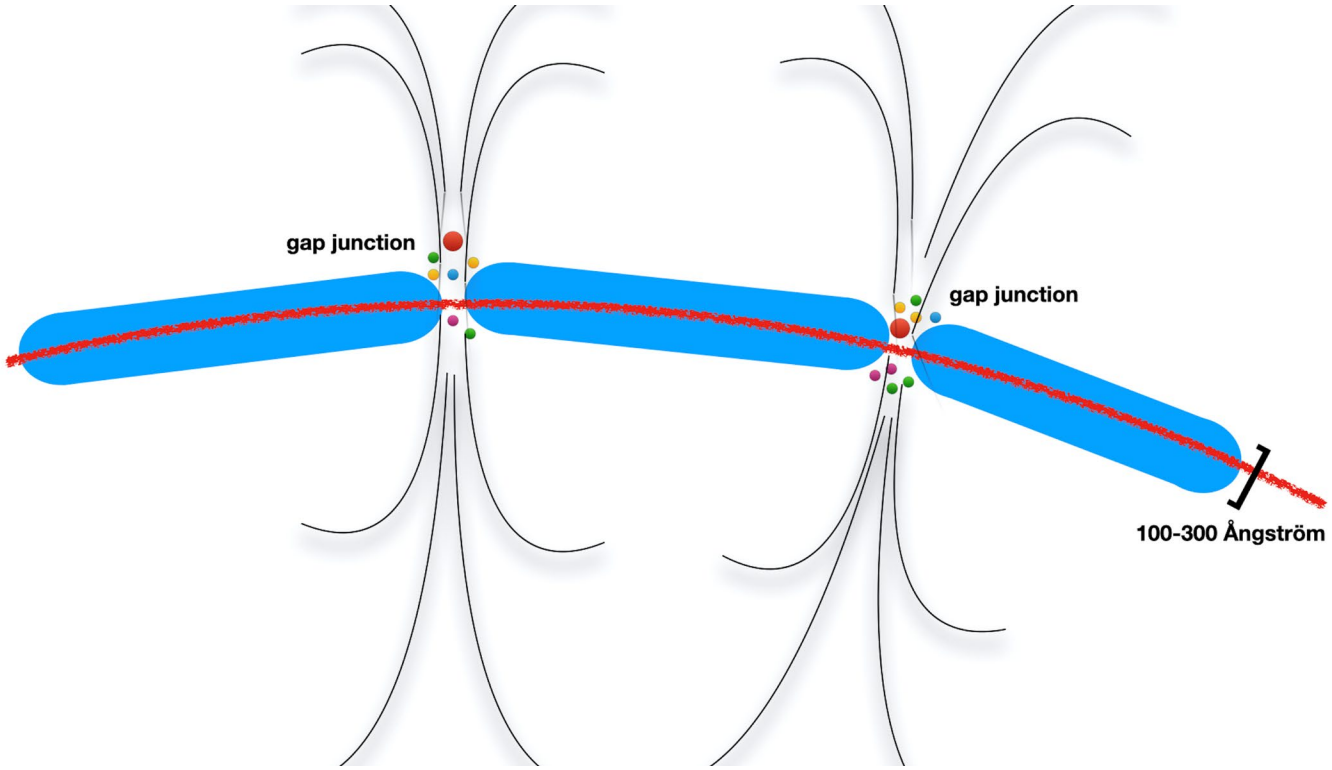

Figure 9. Bound-water cladding around one-dimensional substrate and the Josephson-like gap junctions between water coherence domains (in blue) that, having lost rotational invariance, assume a hollow cylindrical shape enveloping the underlying molecular backbones.

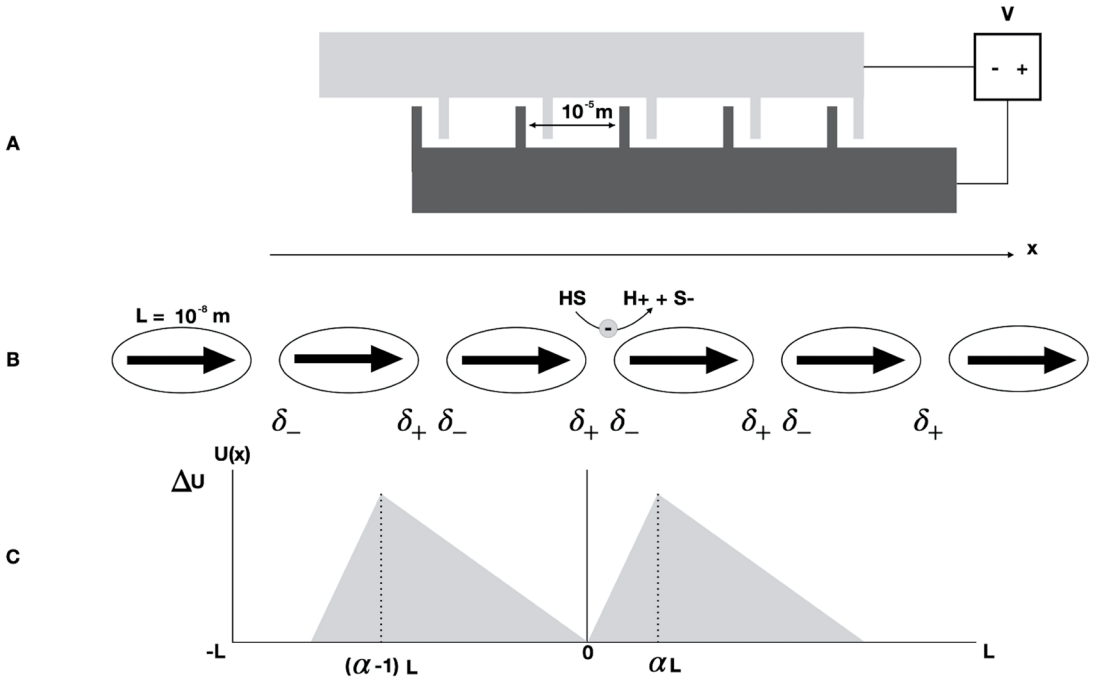

Figure 10. Two models by which an anisotropic periodic potential U(x) can arise - (A) When a voltage difference V is applied to interdigitated electrodes deposited on a glass slide with asymmetrical periodic spacing among "fingers", the resulting potential is spatially periodic but anisotropic (as shown in C-panel). With photolithography, it is possible to achieve a spatial period L for such a structure as small as, or even less than 10−5 m. (B) Sketch of a linear array of dipoles aligned head-to-tail on which a charged Brownian particle (possibly a protein) moves. The individual dipoles could be macromolecular monomers (as tubulins) that aggregate to form an extended linear polymer. The length of the particular monomer is estimated at L ≈ 10−8 m, a reasonable value for many aggregating proteins. If the particle catalyzes the reaction HS → H++S−, for instance, the charge on the particle, and hence its electrostatic potential energy of interaction with the dipole array U(x, t), fluctuates depending on its chemical state. (C) The kind of outcome potential U(x) for both (A) and (B) is approximately an anisotropic saw tooth function U_{saw}, drawn for simplicity as a piece-wise linear function. The amplitude is ΔU, and the wells (potential minima) are spaced periodically at positions iL (with i an integer). The anisotropy is parameterized by α. The amplitude ΔU of the saw tooth potential can be modulated in (A) by using an external switching device to control the applied voltage.

supercurrent of ions on the surface of the water cylinder); and (2) quantized magnetization leading to ion trapping in cyclotron orbits lying on the outer surfaces of the water sleeves (and in the free spaces of the gap junctions), as well as to additional resonance degrees of freedom.

It has been shown (Del Giudice *et al.* 1985) that non-linear molecular interaction in cytoskeletal protein polymer, embedded in coherent water, may sustain the dynamic formation of soliton waves, namely of a spatially confined collective phonon excitation, that does not "spread out" in its high speed over the polymer, neither deforms or collapses by interacting with other solitons and is able to self-regenerating from environmental noise perturbations. The soliton may also transport kinesin along the microtubule (and potentially induce actin-myosin coupling), see Fig. 10.

The formation of spatial regions filled with multiple CDs (supercoherence) may arise only in the presence of other species/solutes, with which the domains can exchange energy in radiation form (photons) or electric charges transferred as catalysis. Liquid water can generate many different levels of coherence, thereby creating a holographic and fractal system (Fig. 11) (holographic means that a part of the overall architecture cannot change without simultaneously modifying all the other levels). Perturbations of the electronic excitation of water molecules may modify the extended coherence producing in turn changes in the interacting species, their distances, and the entire configurational cascade is modified.

We recall that an isomorphism between coherent states and fractals has been demonstrated (Vitiello 2012; 2014). The fractal self-similarity signals that in living matter similar rhythms and oscillation patterns recur at different scales. On this basis rests the compartmentalization of living systems.

Finally, we remark that since a living system has forms and structures, fractal ensemble of work cycles producing niches, compartments, and non-

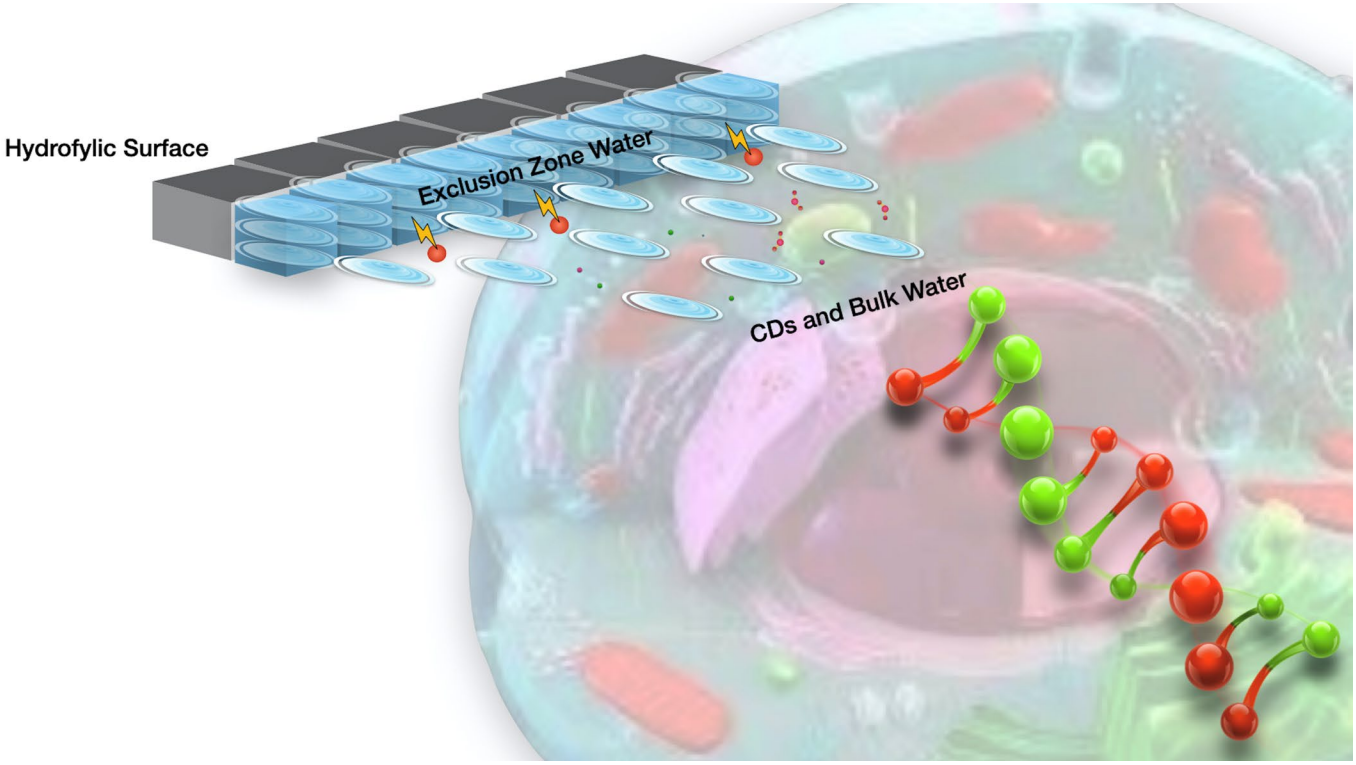

Figure 11. An artistic sketch illustrating the progressive formation of increasingly extended molecular structures (with diverse topologies such as chains, membranes, and vesicles) driven by selective resonance dynamics and energy transfer between molecular partners (monomers). These processes arise from interactions between coherent (interfacial) water and bulk water.

homogeneous subsystems, cannot be described in a simple way solely at a thermodynamic level.

9. The Heart-Brain Dialogue and Concluding Remarks

Our discussions in the previous sections suggest a possible understanding of structuring processes of biomatter in interaction with water (Hasegawa *et al.* 2017). For example, cellular membranes may arise from assemblies of interfaces between biomolecules and structured water (Lambert *et al.* 2012; Meijer & Geesink 2016), leading in turn to the formation of glassy water regions (Debenedetti & Stanley 2003) with filamentation of EM fields. Along these filaments, cytoskeletal protein assemblies can converge, and biochemical reactions can occur in the transition zones of field potentials (Cifra *et al.* 2010; Havelka *et al.* 2011; Kučera & Havelka 2012; Kučera, Havelka, & Cifra 2017).

Closed cavities, membrane-bounded compartments (organelles, cells, tissues, etc.) can sustain standing waves. Thus, not only EM waves, but also pressure-acoustic waves may form node-antinode regions with local concentration or depletion of matter (Pietak 2011; 2012), thus favoring or inhibiting interaction via kinematic (e.g. cymatic) mechanisms, see, e.g., (Jenny 1967; Jenny 2001).

We may conclude our discussion by noting that the Relaxation Response (RR) study, originated from a practical therapeutic need to counteract the etiopathological effects of stress on the heart, helps to see how the biochemical world follows an underlying wave of biophysical changes. It also shows how these studies' results (see Section 1) may be related to the coherent dynamics among the mediators and to the formation of districts, cells, organs, tissues, and dynamic structures. These are organized and positioned to preserve the functioning of the entire living system, at each time, maintaining an equilibrium with its environment, and optimizing the system's overall energy balance.

Each structure thus encodes interactions across multiple scales. We have proposed that the heart, understood as both an EM field and an anatomical-physiological morphology, "conducts" the bodily orchestra. In this view, the heart acts as the primary generator of a large-scale EM field (modulated by its

beat-to-beat different contractions). This is capable of generating vortices and acoustic fields, and of anticipating the brain in perceptual operations, thereby constraining brain activity as a function of the cardiac cycle (Dal Lin, Tona, & Osto 2018; Dal Lin *et al.* 2021; Keppler 2023).

Through a feedback mechanism, if the brain (through semantic conditioning) (Dal Lin, Tona, & Osto 2019; Naviaux 2019) produces a response that diverges from the hearth organization (already structured to respond minimizing the energy) then, at the points of divergence, matter may decohere. This gives rise

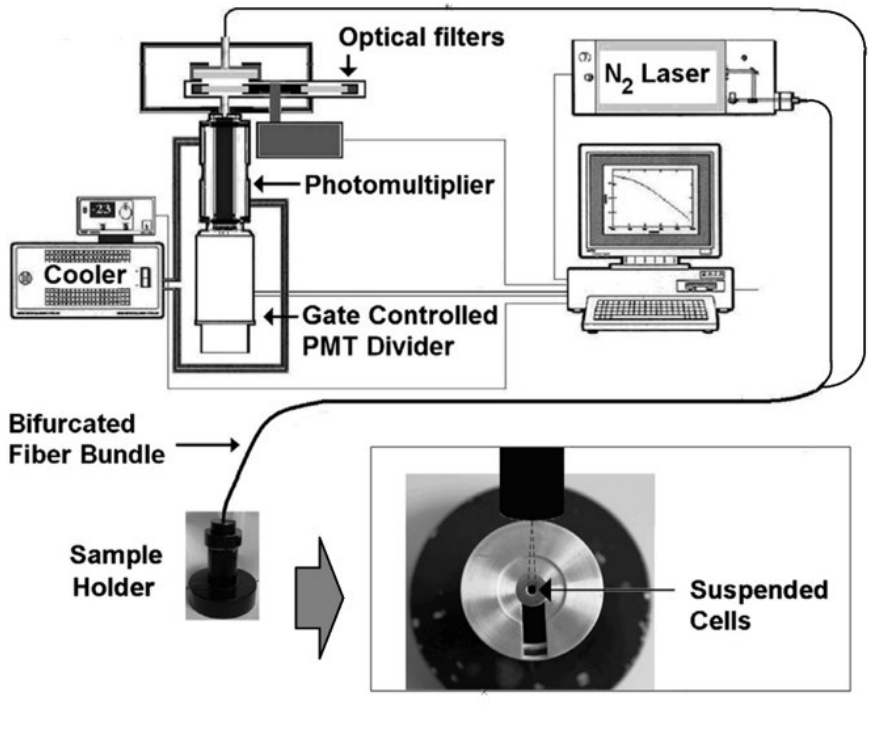

Figure 12. Drawing of the photomultiplier set-up; for more details, please see (Dal Lin, Grasso *et al.* 2020). This biophoton quantification equipment uses a photomultiplier (PMT) enhanced to count single photons. The excitation source is a high-intensity pulsed nitrogen laser that illuminates the sample through an optical fiber. During the laser pulse, an electronic shutter switches off the PMT to prevent damage from the large number of photons scattered by the sample. We use an electronic shutter instead of a mechanical one because it reduces the delay between the laser pulse and the start of data acquisition. The biophoton emission is called "Delayed Luminescence" (DL) and was measured in a time window that starts from about 10 μs after the illumination is switched off and lasts until the signal is clearly distinct from the background. A personal computer equipped with a special multichannel scaler manages the entire data acquisition process. It records the number of photons collected in a time window as a function of time. To reduce noise, we applied a smoothing procedure: we sampled and averaged the experimental points so that the final data are equally spaced on a logarithmic time axis.
The low intensity of the DL signal does not allow high spectral resolution. Therefore, to evaluate the spectrum, we used three broadband interference filters (50 nm FWHM) placed between the sample and the photomultiplier. The central wavelengths of the filters were 450 nm, 550 nm, and 650 nm, respectively.
To reduce background noise, the photomultiplier was cooled to -30 °C. The most important background source in these measurements is represented by the DL emitted by parts of the same apparatus, such as the sample support.
To reduce the required serum volume and eliminate background signals from excitation of the sample containers, we developed a specific sample support. It consists of a hollow cylinder covered by a closing disc with a small 3.5 mm diameter hole (see photo in the insert in Fig. 3). The sample consisted of a "drop" (volume 20–25 μL) supported only by contact with the edge of the circular hole. This eliminated any material behind the sample and therefore spurious components due to support.
A bifurcated optical fiber was positioned just above the "drop" so that only the sample, not the support, fell inside its solid collection corner. In this way, the fiber, connected to both the laser and the PMT, was used both to illuminate the sample and to collect the DL.
To avoid contamination, we replaced the pierced metal disk that closed the sample holder and held up the "drop" at every measurement. Because the signal was low, we averaged 100 runs for each sample to reduce measurement error and increase the signal-to-noise ratio. In addition, we performed two technical replicates for each sample.

to functional disorders, oxidative processes (Michel-Beyerle *et al.* 1976; Steiner & Ulrich 1989; Rodgers 2009; Turro 2011; Al-Khalili & McFadden 2014), mutations (McFadden & Al-Khalili 1999), pathological anatomical alterations (Picard *et al.* 2015), alternative splicing, or modified protein quaternary structures (Dal Lin, Tona, & Osto 2019).

Complementing what is described in previous work (Dal Lin *et al.* 2021), numerous lines of evidence suggest that DNA, particularly in its non-coding regions, is capable of generating excited electronic states such as excimers, singlets, triplets, and quintets (Renati 2021). The decay of these states can occur via photon emission—fluorescence (in the case of singlets) or phosphorescence (triplet decay)—with a spectrum spanning from visible to infrared and ultraviolet (Pietruszka & Marzec 2024). These properties enable the formation of photo-reactive polymeric structures in DNA that can trap, modulate, and transport EM excitations in the form of biophotons, either in coherent or solitonic form (Cacha & Poznanski 2014), thereby suggesting the potential existence of a highly efficient internal communication system.

We have documented an increased presence of such emissions following RR (Dal Lin, Grasso e*t al.* 2020). Please, see Figure 12 for experimental details.

From an anatomo-functional standpoint, the discovery of the Bong Han vascular system—primo vascular system, PVS (Soh, Kang, & Harrison 2012)—has identified a network of filamentous structures distributed capillary like throughout the organism, potentially dedicated to the long-range transfer of photo-electronic signals, analogous to the operating principle of optical fibers (Soh 2004). These structures would represent a functional infrastructure capable of integrating and synchronizing, in real time, cellular and tissue activities, and of enabling bidirectional transmission of bioenergetic information. Functional MRI studies have shown that stimulation of specific points on the body can selectively activate brain regions that appear functionally distinct (e.g., tactile stimulation of a point on the body and activation of the visual cortex), with a correspondence between body points and areas of visceral/neural response (Jones 2002). The speed of information transmission is noteworthy: when the visual cortex is stimulated via light entering the eyes and travelling through the optic nerves, the process takes about 250 ms. Ultrasonic (or tactile) stimulation of an acupuncture point on the foot, by contrast, activates the same cortical area in approximately 7 μs (Renati 2021). Two different communication pathways, each at a different speed, are thus engaged. It has been hypothesized that phonons (associated with ultrasound), introduced at a given point in the body, elicit an almost immediate response from the entire PVS network. This suggests the existence of communication networks complementary to classical neuroelectric pathways, based on rapid transmission via photonic and acoustic signals at the subcellular and tissue levels (Jones 2002).

In summary, these latter observations interweave with heart-brain dialogue mechanisms (Dal Lin, Tona, & Osto 2018; Dal Lin *et al.* 2021), highlighting sophisticated EM, biophotonic, and acoustic communication networks in living systems that operate in close interaction with molecular and anatomical structures, supporting complex phenomena of functional regulation and of response to environmental and therapeutic stimuli (Brizhik *et al.* 2019).

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