Superradiant coherent photons and hypercomputation in brain microtubules considered as metamaterials

Luigi Maxmilian Caligiuri and Takaaki Musha

***Abstract*—**Several studies have suggested the theoretical possibility of considering human brain as supercomputer using superluminal evanescent photons eventually generated inside its microtubules to manipulate quantum bits in brain. In a previous work we have shown that in the water trapped inside brain microtubules could exist the conditions to allow a spontaneous QED quantum vacuum phase transition towards a macroscopic coherent quantum state characterized by a phased oscillation, at a rescaled frequency, between the water molecules states and an auto-generated electromagnetic field associated to a suitable electronic transition in them. As a result a self-trapped field of superradiant superluminal photons is just generated inside microtubules, characterized by an evanescent tail whose penetration depth is greater than the thickness of microtubules cylinder. In this way the interior of the brain MT cylinders can be considered as a resonant cavity for such superradiant photons whose refraction index depends on the rescaled coherent oscillation frequency. On the other hand it is already theoretical known and experimentally proven that a near perfect tunneling and amplification of evanescent electromagnetic waves is possible in a waveguide filled by a metamaterial. In this paper, basing on the consideration of some structural analogies between man-made metamaterials and some natural biological structures, we just propose the idea to interpret the inner medium of the brain microtubules cylinder as having the properties similar to those characterizing metamaterials and so able to specifically enhance the propagation of evanescent photons inside the neurons.

***Keywords*—**QED Coherence, Evanescent Photons, Metamaterials, Microtubules, Quantum Vacuum, Water.

I. Introduction

FOR many times the possibility to interpreter, in the light of quantum physics (QP), brain functions (as well as many other physical phenomena) was hindered by the deeply erroneous conviction that quantum physics was limited to the description of microscopic world. The fallacy of this belief firstly lies in the ascertainment that QP actually concerns not just phenomena occurring in the microscopic world only but, more correctly, all the phenomena involving quantized exchanges of energy. Fundamental examples coming from condensed matter physics [1,2,3,4] have proved the rightness of this statement as, for example, the discovery of superconductivity (cold and hot) and ferromagnetism, all showing the presence of a quantum behavior over macroscopic (with respect the atomic or molecular size) distances and at relatively high temperatures.

One of the most fascinating connection between QM and biological processes could be related to the emergence of consciousness, the formation of memory and computational functions in human brain. In particular, the unity and non-local manifestations of consciousness [5-7] could be naturally explained in terms of quantum coherence and long-range correlation as well as the non-algorithmic and non-computational features of certain brain functions, as argued by Penrose [8,9]. Quantum mechanics is also a good candidate to explain the unique distributed features of some brain's functions as memory storage and perceptual processing for example in connection to the so-called holographic model of brain firstly proposed by Pribram [10] in which such functions are linked to the associative features of parallel distributed processes at the basis of holographic optical techniques. The general requirement of non - locality and cooperative activity is also strongly suggested by the persistence of memory and perception functions in brain, even in the presence of extensive tissue damage [11].

After the Schrodinger's intuition, expressed in his book "What is life?" [12], the first systematic approach to a quantum interpretation of biological process dated back to the model proposed by Frohlich [13] several years ago. He suggested the occurrence, in biological matter, of macroscopic quantum phenomena able to explain the energy transport without loss in the living organisms and signal transfer based on collective coherent oscillations associated to a branch of longitudinal electric modes in the frequency range

$$\nu_{coh,F} \sim 10^{11} - 10^{12}\, s \tag{1}$$

also known as Frohlich frequency. So in living systems, according to Frohlich's model, energy could be stored in a thin two - dimensional layer placed beneath the cell membrane, that in this way would act as a biological superconducting medium, under dipolar propagating waves without thermal loss [13].

Subsequently Popp [14], basing on a different standpoint, proposed the idea that also the weak emission of photons in the visible range of electromagnetic spectrum by living

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organisms, the so-called “biophotons”, could be related to a sort of coherent mechanism typical of living systems.

The consistent interpretations of quantum behavior in living organisms given by Frohlich's and Popp's models also found a further theoretical foundation in the analysis given by Umezawa [15] within the framework of quantum field theory, who suggested the presence, in brain's cells, of a spatially distributed system characterized by the full range of quantum mechanical degrees of freedom subjected to quantum phenomena. Later Davydov [16] extended some considerations of the Frohlich's model, whose dipolar coherent oscillations were restricted to thin layers adjacent to cell membranes, by proposing the existence of “solitonic excitation states” responsible for the dissipation-free energy waves propagating along $\alpha -$ helices in proteins.

In 1990’s Hameroff and Penrose [8,9,17] suggested a primary role of quantum effects in brain functioning and, in particular, in the emergence of consciousness, by considering the dynamics of microtubules (MT) of brain cells. In their model they pictured the tubulin dimer units of MT as quantum systems described by a coherent superposition of two-levels quantum states, corresponding to the two conformations of tubulin proteins ($\alpha -$ and $\beta -$ tubulin), depending on the position of the unpaired charge of $18e$ relative to pocket.

In particular, Hameroff suggested [18] that MT could be considered as waveguides for photons and as holographic information processors, also due to their periodic lattice structure (providing “periodically arrayed slits”) through which photons can pass. From the standpoint of QP, this model [15] considers the phenomenon of the so-called “superradiance” potentially occurring, under suitable conditions, in the water molecules contained in the MT inner volume, namely a quantum collective behavior of water molecules and electromagnetic field modes able to convert the perturbative thermal and molecular disordered oscillations into coherent photon modes inside MT, whose first theoretical treatment was due to Del Giudice, Preparata and Vitiello [19] by the model of water as a free electric dipole laser.

According to the latter, in fact, the coherent interaction between the “matter field” associated to water molecules and a self-generating quantized electromagnetic field arising from QED quantum vacuum, spontaneously occurring under suitable boundary condition on matter density and temperature, is very strong within a spatial region of the order of

$$L \sim 2\pi/\omega_0 \tag{2}$$

where ω_0 (in the units system in which $c = \hbar = 1$) is the energy associated to the transition between a given couple of levels of energy of the matter quantum field corresponding, for the transitions between the ground state and the low-lying states of water molecule rotational energy spectrum (of the order of $4\,meV$) , to few hundreds of microns. Within this spatial region, also know as “coherence domain” (CD), the time scale associated to coherent interaction is of order of $10^{-14}\,s$, namely much shorter than the typical time scale connected to short-range interactions.

This coherent dynamics also determines an extended oscillation polarization field able to correlate an high number of water electric dipoles. In this way the coherent interaction between water electric dipoles and the radiating electromagnetic field is able to generate stable and ordered structures in macroscopic spatial regions. Furthermore, due to coherence, the photons associated to this electromagnetic field would be characterized by the so-called “self-induced transparency” according to which they are able to penetrate the optical medium where they propagate as it were made transparent by the photon field itself thus potentially leading, inside cytoskeletal MT of brain, to a sort of coherent optical supercomputers able to enormous elaboration capabilities.

In particular, according to Jibu et al [11], the photons composing the coherent electromagnetic field inside CDs entangle the cytoskeletal protein and the MT quantum sates of a given neuron link to those of other neurons by the tunneling of such coherent photons through biological membranes. In this way these authors argued that also consciousness could arise from such coherent dynamics and, in particular, from the creation-annihilation dynamics of a finite number of evanescent photons in brain.

As pointed out by Recami [20,21] tunneling photons moving in an evanescent field can be characterized by a superluminal group velocity or, equivalently by a negative square mass of the photons belonging to the evanescent field that can be shown by considering that a quantum evanescent photon satisfies the Klein-Fock-Gordon equation, namely (in one dimension):

$$\left[-\left(1/c^2\right)\left(\partial^2/\partial t^2\right) + \nabla^2 - m_0^2 c^2/\hbar^2\right]\psi\left(x,t\right) = 0 \tag{3}$$

where c is the velocity of light in vacuum, m_0 the absolute value of the proper mass of the evanescent photon. The solution of (3) is given by

$$\psi\left(x,t\right) = A \cdot \exp\left[-\left(p \cdot x + E \cdot t\right)/\hbar\right] \tag{4}$$

corresponding to a particle characterized by an imaginary rest mass $i \cdot m_0$ moving at a superluminal velocity and satisfying the relativistic relation

$$E^2 = p^2c^2 - m_0^2c^4 \tag{5}$$

where, as usual, E is the total energy and p the momentum of the particle.

Then, according to this picture, superluminal photons traveling in an evanescent mode arising from coherent macroscopic quantum system inside MT could be able to realize, through a long-range order in living systems, an optical computing network in which brain’s MTs can achieve quantum bit computation on large data set, so practically realizing hypercomputing performance with respect conventional processors as suggested by Musha [22]. Furthermore, as shown by Caligiuri [23] in the general context of Special Theory of Relativity and by Ziolkowski [24] in relation to electromagnetic metamaterials, superluminal propagation in principle doesn't violate causality.

Nevertheless Georgiev [25] observed the wavelength of coherent photons associated to the energy difference of $4\,meV$ between the two eigenstates of water molecule involved in superradiant water model, equal to $\lambda \simeq 310\,\mu m$ (i.e. lying in the infrared range of electromagnetic spectrum), is not comparable with the typical length $l \sim 1\,\mu m$ of a moderate sized MT, being $\lambda \gg l$.

Consequently, according to this last statement, there wouldn't be any nodes and anti-nodes inside MT and there could be no way to use superradiant emission of infrared photons to manipulate the qubits inside the MT cavities or centrioles in a fashion similar to the use of standing wave lasers in the ion trap computation.

In addition, Mavromatos [26], also referring to the Hameroff-Penrose model, recently discussed the role of environmental decoherence on the quantum system composed by brain's MT, observing that, even for in vivo MT, the effect of environmental interaction on this coherent system cannot be ignored and proposed a "quantum electrodynamics cavity model" for MT, based on the consideration of the electromagnetic interaction, at a frequency $\omega \sim 6 \cdot 10^{12}\,Hz$, between the electric dipole moments of tubuline protein dimer units and the corresponding dipole quanta in the thermally isolated water inside the brain's MT, for which he calculated an environmental decoherence time of $O\left(10^{-6} - 10^{-7}\right)s$, a time scale much shorter than that required for conscious perception, but sufficient to allow a loss-free energy transfer and signal propagation along a moderately long MT ($l \sim 1\,\mu m$).

In this paper we propose an alternative theoretical model, already successfully applied by Caligiuri to the study of biophotons emission [27], also based on the consideration of the QED coherence in the water inside brain's MT, but considering electronic transitions rather than rotational energy levels in water molecules, able to overcome both the critical points revealed by Georgiev and Mavromatos as well as to explain the origin of superluminal evanescent photons capable to be used for the manipulation of qubits in brain [28].

This model also allows us to interpret the MT structure as a waveguide for the coherent e.m. field generated inside the water CD whose refraction index results an imaginary quantity for the studied system. This particular feature, in addition to the consideration of a remarkable similarity between the e.m. metamaterials (MTM) and the cross section of some natural biological structures containing MT, suggests the idea to consider the inner medium of the brain microtubules cylinder as having the properties similar to those characterizing MTM.

On the other hand the possibility to realize the amplification (of many orders of magnitude) and a near-perfect tunneling of an evanescent e.m. field has been already firmly established both from a theoretical and experimental point of view by J. D. Baena et al. [29] that have shown the occurrence of this phenomenon when considering an evanescent e.m. field in a waveguide partially filled with a MTM characterized by suitable features.

The proposed model then present a possible theoretical frameworks to explain the enhancement and propagation of superluminal coherent photons inside neurons also confirming the idea that coherent dynamics of water inside MT could play a primary role in the establishment of long-range order in living organisms and in the formation of high-grade functions in brain as, for example, hypercomputation and, eventually, consciousness.

II. A SYNTHETIC OVERVIEW OF QED COHERENCE IN CONDENSED MATTER

A. *Quantum Vacuum fluctuations and energy shift in atoms and molecules*

It is a well-known phenomenon in modern physics that the energy of a Hydrogen atom varies as a consequence of the coupling of the electric current associated to the orbiting electron to the electromagnetic field of the QV fluctuations. This effect. called "Lamb – shift", discovered in 1945 and only later understood, demonstrates, together with other experimental evidences (as, for example, the Casimir effect and the radiative correction of the particles masses) the direct interaction between QV and atoms and that this interaction is able to modify the energy of the latter even meaningfully. In modern physics, in fact, the physical vacuum cannot be considered, due to Heisenberg uncertainty principle, as a void but as a physical entity manifesting a complex and fundamental background activity in which, even in the absence of matter, processes like virtual particle pair creation – annihilation and electromagnetic fields fluctuations, known as Zero Point Field (ZPF) or QV fluctuations, continuously occur.

According to the framework of QED coherence in condensed matter, originally developed by Preparata [30] and applied to living systems by Preparata, Del Giudice et al. [31-39], starting from a well-known behavior of electromagnetic and matter quantum fields, under suitable boundary conditions (almost always verified in the condensed matter and living organisms as well), a coherent electromagnetic field, oscillating in tune with all the matter constituents, spontaneously emerges from the self-produced electromagnetic field.

In particular it has been shown [30] that, above a critical density $\left(N/V\right)_{crit}$ and below a threshold temperature T_0, an ensemble of atoms or molecules, placed in the empty space (namely without any matter or radiation field different than ZPF), spontaneous "decays" into a more stable state (characterized by lower energy and so strongly favored) in which all the matter components are phase correlated among them by means of the action of an electromagnetic field oscillating in tune with them too, confined within a defined spatial region, called "Coherence Domain" (CD), associated to the wavelength of the tuning electromagnetic field.

The arising of this physical coherent state can be understood by considering that, according to quantum field theory, matter and fields continuously perform quantum fluctuations. The same types of fluctuations also characterize, as seen above, the QED QV.

We consider the matter system to be composed of electrical charged particles (electrons and nuclei) characterized by a discrete energy spectrum $\left\{E_i\right\}$ and indicate with "0" its fundamental state (whose energy is

$E_0 = \hbar\omega_0$) and with "k" a generic excited state (with an associated energy $E_k = \hbar\omega_k$). A vacuum fluctuation able to coupled to the systems and excite the state k (from the fundamental one) must then have a wavelength $\lambda = hc/\delta E$ where $\delta E = E_k - E_0$. The probability of this coupling with the excitation of state k is quantified by the "oscillator's strength" for the transition $0 \to k$, given by [30]

$$f_{0k} = \left(2m_e/3\omega\left|E_k - E_0\right|\right)\sum_j\left|\left\langle 0\left|\vec{J}_j\right|k\right\rangle\right| \tag{6}$$

where ω is the frequency of the exciting electromagnetic field, m_e the electron mass and $\vec{J}$ the electromagnetic current density operator. For an atom or molecule with n electrons, f must follow the rule

$$\sum_k f_{0k} = n \tag{7}$$

Now let's consider the volume of space $V = \lambda^3$ "covered" by an oscillation of the QV electromagnetic field resonating with them, supposing it contains N atomic or molecular species, and let be P the "Lamb – shift type" probability that a photon "escapes" from QV, couples with an atom or molecule and puts it in a given excited state. The overall probability of coupling for the N constituents is then

$$P_{tot} = P \cdot N = P\left(N/V\right)V = P\left(N/V\right)\lambda^3 \tag{8}$$

that is proportional to the matter density. So, when density exceeds a particularly high value, almost every ZPF fluctuation couple with the atoms or molecules in the ensemble. This condition starts the "runaway" of the system from the perturbative ground state, in which matter and quantum fluctuations are uncoupled and no tuning electromagnetic field exists, to a coherent state in which, within a CD, a coherent electromagnetic field oscillated in phase with matter determining a macroscopic quantum state in which atoms and molecules lose its individuality to become part of a whole electromagnetic field + matter entangled system.

B. The equations of coherence and the "runaway" towards the CGS

The evolution of such a system can be characterized mathematically [30,32] considering, for simplicity, a two-levels matter system described by the matter field $\chi_l\left(\vec{x},t\right)$ with $l = 0,k$ and an electromagnetic field characterized by its vector potential $\vec{A}\left(\vec{x},t\right)$. If we neglect the spatial dependence of both the fields (since they can be assumed slowly varying within the CD) the dynamic equations, describing the time-evolution of the electromagnetic field+ matter interacting ensemble, are given by

$$\begin{gathered} i\dot{\chi}_0\left(\tau\right) = g\chi_k\left(\tau\right)A^*\left(\tau\right) \\ i\dot{\chi}_k\left(\tau\right) = g\chi_0\left(\tau\right)A\left(\tau\right) \\ -\frac{1}{2}\ddot{A}\left(\tau\right) + i\dot{A}\left(\tau\right) - \mu A\left(\tau\right) = g\chi_0^*\left(\tau\right)\chi_k\left(\tau\right) \end{gathered} \tag{9}$$

where

$$g = eJ\left(8\pi/3\right)^{1/2}\left(N/2V\omega_k^3\right)^{1/2} \tag{10}$$

and

$$\mu = \left(e^2\lambda/\omega_k^2\right)\left(N/V\right) \tag{11}$$

being A the directional averaged vector potential and $\tau = \omega_k t$.

It is easy to show [30,35,37] the differential system (9) admits the following constants of motion

$$\chi_0^*\chi_0 + \chi_k^*\chi_k = 1 \tag{12}$$

$$Q = A^*A + \frac{i}{2}\left(A^*\dot{A} - \dot{A}^*A\right) + \chi_0^*\chi_0 \tag{13}$$

$$H = Q + \frac{1}{2}\dot{A}^*\dot{A} + \mu A^*A + g\left(A^*\chi_k^*\chi_0 + A\chi_0^*\chi_k\right) \tag{14}$$

in which the quantity Q can be considered as the "momentum" of the system and H its Hamiltonian divided by N . In order to study the time – evolution of the system we start from the "perturbative" initial state of QED defined by

$$A\left(0\right) \sim N^{-1/2} \to 0,\ \chi_k\left(0\right) \sim N^{-1/2} \to 0,\ \chi_0\left(0\right) \sim 1 \tag{15}$$

from which the system will "decay" towards the coherent stable state characterized by $A \gg 1$ and $\chi_k \gg 1$. The short-time behavior of the system can be studied [8] by differentiating the third of (9) and substituting it into the second one, so obtaining

$$-\frac{1}{2}\dddot{A}\left(\tau\right) + \ddot{A}\left(\tau\right) + i\mu\dot{A}\left(\tau\right) + gA^2\left(\tau\right) = 0 \tag{16}$$

whose algebraic associated equation is

$$a^3/2 - a^2 - \mu a + g^2 = 0 \tag{17}$$

As know from the general theory, the (17) will have exactly three solutions (real or complex). The "decay" towards the coherent state will occur when the values of μ and g are such to have only one real solution of (17), the other two complex-conjugate ones just describing the exponential increase of $A\left(\tau\right)$ able to overcome its nearly zero initial value and create the coherent tuning field. It can be shown [30-37] that this occurs, for a given μ , when

$$g^2 > g_{crit}^2 \tag{18}$$

where

$$g_{crit}^2 = 8/27 + 2\mu/3 + \left(4/9 + 2\mu^2/3\right)^{3/2} \tag{19}$$

In summary, when condition given by (18) is satisfied, the system will undergo a truly "phase transition" from the incoherent pertubative ground state (PGS) in which the electromagnetic and matter fields perform Zero – Point very weak uncoupled fluctuations only, towards the coherent ground state (CGS) in which a strong electromagnetic field arises from QV and couples with the oscillations of the matter fields tuning all the matter constituents to oscillate in phase with it and among themselves by means of it. But why the should the system do "decide" to run away towards CGS ?

The answer is, as above anticipated, this state is energetically favored so representing the "true" ground state of the electromagnetic field + matter system. This can be rigorously demonstrated by mathematics [30], but a simple physical argument runs as follows.

If we indicate as δE_{ZPF} a spontaneous QED QV fluctuation able to excite some atomic / molecular level of the matter constituents of the given ensemble and with δE_{int} the energy shift induced in them by the interaction with the electromagnetic field of Zero Point (i.e. a Lamb-shift type term), the total energy fluctuation is given by

$$\delta E = \delta E_{ZPF} - \delta E_{\text{int}} \tag{20}$$

where the minus sign before δE_{in} is due to the fact the Lamb-shift term reduce the energy of atomic/molecular constituent, since it introduces in the atomic Hamiltonian the interaction term $e\vec{J} \cdot A\left(\vec{x},t\right)$ with

$$\vec{J} = -\sum_{l=1}^{Z} \vec{p}_l \big/ m_e \tag{21}$$

where Z is the atomic number and $\vec{p}_l$ is the momentum operator of the l-th electron. It can be shown [30,32] that, for an ensemble of N atoms/particles interacting with ZPF, we have $\delta E_f \propto N$ while $\delta E_{\text{int}} \propto N\sqrt{N}$ so we can write

$$\delta E = aN - bN\sqrt{N} \tag{22}$$

in which $a > 0$ and $b > 0$ are two constants of proportionality depending on the system properties. From (22) we see that there exist a definite value of $N = N_{crit}$, depending on a and b, such that, when $N \geq N_{crit}$ (namely just the condition for the runaway of the system towards the coherent ground state) we have

$$\delta E < 0 \tag{23}$$

The result given by (23) has a very deep physical meaning since it implies some remarkable consequences [30-37]:

a) the CGS is the "true" ground state of the system because its energy is lower, of the quantity δE (gap), than the energy of "gas-like" PGS in which we only have the independent Zero-Point fluctuations of electromagnetic and matter components while, in the CGS, the matter constituents oscillates in tune with a non fluctuating "strong" electromagnetic field;

b) the "decay" of the system from PGS to CGS can be considered as a truly phase transition, corresponding to the release of a quantity of energy just equal to the gap δE to the environment, so characterizing the electromagnetic field + matter ensemble as an open system;

c) the tuning of the electromagnetic field with the matter field determines a renormalization of frequencies of the matter system so that the common oscillation frequency of electromagnetic field and matter field is given by $\omega_{coh} < \omega_{fluc}$, where $\omega_{fluc} = c^2 \big/ \lambda_{CD}$ is the frequency of the QV fluctuating electromagnetic field able to excite the level k and whose wavelength λ_{CD} defines the spatial extension of CD;

d) the coherent electromagnetic field generated inside a CD shows an evanescent tail at its boundary, determining a superposition between the "inner" electromagnetic fields of the neighboring coherence domains. This superposition makes it possible the interaction between different CDs giving rise to the coherence among them also known as "supercoherence" so explaining the physical origin of long-range and stable correlation between a very high number of matter components in living organisms.

As shown by the above discussion, the formation of CD is strictly related to the QV energy density dynamics: the energy needed for the generation of the coherent electromagnetic field is "extracted" from QV (the photons transferred from random quantum fluctuations to tuning electromagnetic field) whose energy density decrease then determining the formation and sustain of the coherent state and the release of the phase transition energy δE to the environment.

III. QED "ELECTRONIC" COHERENCE IN WATER INSIDE BRAIN MICROTUBULES

A. Water critical density inside MT and the transition towards coherent state

As known microtubules are rigid polymers consisting of groups of protofilaments, of length ranging between $1 - 50\,\mu m$ [26], cylindrically shaped with an outer and inner diameter respectively of about $25\,nm$ and $15\,nm$ (see Fig. 1).

They are composed by structural subunits, the tubulin heterodimers (of length about $8\,nm$), in turn containing the $\alpha -$and $\beta -$ tubulin having an high electric dipole moment (about $10^{-26}\,C \cdot m$) [26] and determining the remarkable electric polarity of MTs that make them very sensitive to electromagnetic field. The mechanical properties of MTs have been studied in details by means of many biophysical techniques such atomic force microscopy, thermal bending and single molecule [38].

Specifically, for the purpose of this paper, we focus on the inner hollow volume of MT that can be assumed to be "filled" with (thermally) isolated water [26], showing in the following that, under the boundary conditions averagely satisfied inside the brain MTs, it undergoes a spontaneous quantum phase transition towards a coherent state in which an electromagnetic field oscillates in tune with the water matter field between two energy levels corresponding to an electronic transition of water molecule.

The coherent dynamics and thermodynamics of liquid water has been analyzed in series of papers [33-37] showing very peculiar and unthinkable features, whose detailed discussion can be found in the cited references. Here we recall some of these that will be specifically used in the present work.

As we have seen above, the “runaway” of a two-levels matter system from PGS to CGS will spontaneously occur when, by (18), $g^2 > g_{crit}^2$, so in order to discover if the considered system will undergo or not the needed superradiant phase transition from PGS we need to determine the specific value of g_{crit} for our system and the correspondent critical density $\rho_{crit} = m_{H_2O}\left(N/V\right)_{crit}$ .To this aim, in the coherent equations (9), the coupling factor g can be written, in the specific case of water, as [35]

$$g = \left(2\pi/3\right)^{1/2}\left(\omega_p/\omega_0\right)^{1/2} f_{01}^{1/2} \tag{24}$$

in which f_{01} is the oscillator strength f_{nk} for the electronic energy transition $0 \leftrightarrow 1$ and ω_p is the plasma frequency given by

$$\omega_p = \left(e/m_e^{1/2}\right)\left(N/V\right)^{1/2} \tag{25}$$

$$\mu = -\left(3/2\right)\left(\omega_p/\omega_0\right)^2 \sum_n f_{nk}\,\omega^2 \Big/ \left[\left(E_n - E_k\right)^2 - \omega^2\right] \tag{26}$$

and the oscillator strength for the electronic transition $n \leftrightarrow k$ is given by (6). In [35] the values of g^2, μ and ρ_{crit} related to the first “low-lying” levels of water molecule has been calculated, showing that that smallest value of $\rho_{crit} = 0.310\,g \cdot cm^{-3}$ corresponds to the transition from the ground state to the level at $E = 12.06\,eV$, namely to a $5d$ excited electronic state of water molecule just below the ionization threshold of $12.60\,eV$.

When the water system reaches this density value, the Quantum Vacuum fluctuations with frequency $\omega = \omega_0 = 12.06\,eV$ start to build up coherently with those of the matter field at the same frequency, determining the “runaway” of the system towards the CGS as discussed above. From this point on, the matter + electromagnetic field system behaves as a macroscopic quantum system oscillating with a common frequency ω_{coh} and all the other energetic levels will be totally ignored by the system evolution.

It is now important to note that the value of critical density required for the runaway is compatible with the estimated density of water inside brain MT, $\rho_{water,MT}$. In fact, assuming for the brain an average temperature $T \sim 37\,°C$ and a MT cavity volume [26] $V_{MT} \sim 5 \cdot 10^{-22}\,m^3$ for a moderately long ($l \sim 10^{-6}\,m$) MT, we have

$$\rho_{water,MT} \sim 0{,}993\,g \cdot cm^{-3} > \rho_{crit} \tag{27}$$

showing the existence of the conditions, inside MT inner volume, required for the superradiant phase transition of water towards the coherent state.

The key point to stress now is that the energy level $\omega_0 = 12.06\,eV$ correspond to a CD whose “size” is, by (2) of order of

$$L_{CD} \sim 0.1\,\mu m \tag{28}$$

that is about $1/10$ of the average length of a moderately sized MT and, in particular, of the order of magnitude of the MT dimers ($\sim 8\,nm$).

The rough estimate given by (28) is very important since it shows that superradiant photons, generated in coherent electromagnetic field oscillating in phase with water molecules inside MT coupled to the electronic transition from the ground state to the energetic level at $12.06\,eV$, are characterized by a wavelength much shorter than the typical length of MT so allowing the formation of nodes and antinodes within the inner MT cavities.

This very important result completely overcome the actual trouble raised by Georgiev with respect the infrared superradiant photons considered in the theoretical models of coherence in MT presented so far.

As recalled in the above discussion, the coherent dynamics inside CD determines a rescaling of the frequency ω_{coh} of the common oscillation of electromagnetic field and matter to a lower value with respect that of ω_0 characterizing the perturbative state in which they are out of phase. It has been shown [30,34,35,37] the “new” value of frequency to be

$$\omega_{coh} = \left|1 - \dot{\phi}\right| \omega_0 \tag{29}$$

where ϕ is the phase factor ruling the behavior of the vector potential $A\left(\tau\right) = A_0 \exp\left[i\phi\left(\tau\right)\right]$. It is interesting to note that, in the case of water [30,34-37], $\omega_{coh} \sim 10^{-2}\omega_0$, determining an energy gap per molecule $\delta E/N \sim -0.26\,eV$.

B. About the photon mass value in the water coherence domains inside MT and the evanescent field of superluminal photons

One of the most important consequences of coherent dynamics, deriving from the frequency rescaling of (29), is that the superradiant photon “mass” acquires an imaginary value inside the coherent electromagnetic field. This can be easily seen by using (2) and the Einstein equation for a the photon, obtaining

$$\begin{aligned} & m^2c^4 = \\ & = \hbar\left(\omega_{coh}^2 - 4\pi^2c^2/\lambda_{CD}^2\right) < \hbar\left(\omega_0^2 - 4\pi^2c^2/\lambda^2\right) = 0 \end{aligned} \tag{30}$$

so implying $m = i \cdot m_0$, where m is the photon mass inside the CD, namely just the condition, given by (5), associated to the existence of superluminal photons ! Now we have obtained our second important result: inside the CDs originated in brain’s MTs by the coherent dynamics of water, the superradiant photons, populating the coherent electromagnetic field tuned with matter field, can be considered as moving at a superluminal velocity inside the CD

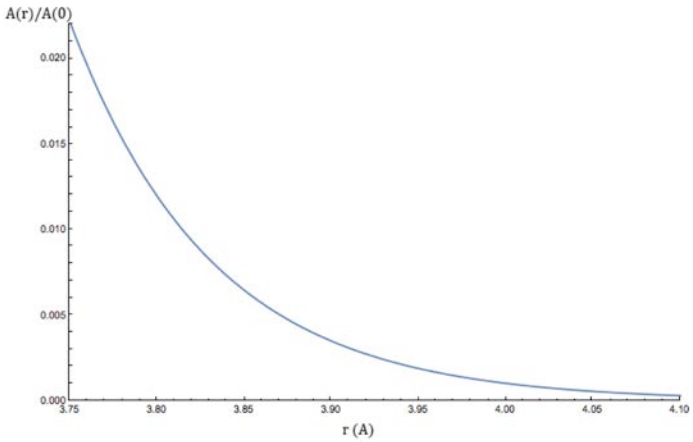

Fig. 2 tail of coherent electromagnetic field of a water CD

itself. Furthermore, the condition (30) also states that the above electromagnetic field is "trapped" inside the CD, thus preventing its dissolution by radiating the coherent field towards outside.

Now, it is then interesting to better investigate the spatial behavior of the coherent solution for the electromagnetic field given by (9). As derived in [30,35] the spatial dependence of the electromagnetic amplitude $A\left(\vec{x},t\right)$ can be given, considering the spherical symmetry of the problem, by the following equations

$$\begin{cases} A\left(\vec{x},t\right) = A\left(0\right)\left(\sin\omega_0 r/\omega_0 r\right)\cdot\exp\left(-i\omega_{coh}t\right),\, r < r_{coh} \\ \left(-\omega_{coh}^2 - \nabla^2\right)A\left(\vec{x}\right) = 0,\, r > r_{coh} \end{cases} \quad (31)$$

where r_{coh} is the "radius" of the CD and the second equation means that, outside the CD, $A\left(\vec{x},t\right)$ satisfies a free field equation. Now using the fact that $\nabla^2 A \sim \omega_0^2 A\left(r\right)$ we can write

$$\left(d^2/dr^2\right)\left(r\cdot A\right) - \left(\omega_0^2 - \omega_{coh}^2\right)\left(r\cdot A\right) = 0 \quad (32)$$

that, as can be easily seen, is characterized by an exponential decaying solution

$$A\left(r\right) \sim \exp\left(-r\sqrt{\omega_0^2 - \omega_{coh}^2}\right) \quad (33)$$

showing the presence of an "evanescent" electromagnetic field at the borders of the CD. In particular, by imposing the matching, at the CD boundary $r = r_{coh}$, between the exponential solution given by (33) and the first of (31) and recalling that $\omega_0 \gg \omega_{coh}$, we obtain

$$r_{coh} \simeq 3\pi/4\omega_0 \quad (34)$$

that represents a better estimate of the dimension of CD. For the case of water with $\omega_0 = 12.06\,eV$ we have

$$r_{coh} \sim 3.75\cdot 10^{-8}\,m \quad (35)$$

that further confirms our previous result of (28) showing, in particular, that the cavity inside MT can be though as "filled" with water CDs associated to the coherent dynamics related to the electronic transition from the ground state to the level at $12.06\,eV$. The superradiant "evanescent" field is then given by

$$\begin{aligned} A\left(r\right) &\simeq \left(A\left(0\right)/\sqrt{2}\right)\times \\ &\times\left(\exp\left[-\sqrt{\omega_0^2 - \omega_{coh}^2}\left(r - r_{coh}\right)\right]/\omega_0 r\right) \end{aligned} \quad (36)$$

whose profile is shown in Fig. 2. Another very meaningful consequence of the above result is that the coherent electromagnetic field resulting from the tuned interaction between matter and electromagnetic field inside the CD has a "tail" extending outside it, under the form of evanescent field, whose spatial extension makes it able to overlap the electromagnetic field associated to the neighborhood CDs.

According to this mechanism, contiguous CDs can interact each other realizing the long-range correlation need for the implementation of biological functions. In particular, this tail allows the evanescent electromagnetic field associated to the water CDs inside MT to "cross" the MT wall and interact with the biological structures placed on it and in its neighborhood.

The existence of this "evanescent" electromagnetic field, emerging from the water CDs, then theoretically suggests, on a robust QFT basis, a possible physical mechanism able to explain the tunneling of superluminal photons, trapped inside water CD, towards the "outside" environment.

C. Thermodynamics of water inside brain MT and the environmental decoherence problem

In the coherent state so far analyzed, the tuned oscillation between matter and electromagnetic field forbids any thermal fluctuation and then it is virtually associated with a thermodynamic absolute temperature $T = 0$. In this condition, no energy inflow from the environment is then possible. This is prevented by the energy gap characterizing the coherent state after the release of the energy δE .

Nevertheless, if the temperature of the environment increases to a value $T > 0$ (as, for example, occurs for CD placed in a thermal bath at $T \neq 0$), the collisions between the fluctuating environment molecules (thermally excited) and the components of a CD, could transfer to it the energy gap per atom/molecule δE , able to put some of them out of tune with the electromagnetic field.

This environmental decoherence determines the "expulsion" of some matter components from the CD and the formation of an incoherent fraction of matter system at the boundaries of CD.

So, in order to ensure the formation and the persistence of CDs in the water inside brain MT, the fraction of coherent water has to be sufficiently high.

In order to verify the occurrence of this condition in brain MT, we'll consider the expression of coherent water fraction F_{coh} as a function of absolute temperature T obtained in [30,35], namely

$$F_{coh}(T) = 1 - (64/9)\int_0^{3/4} x^2 F(x,T)\,dx \quad (37)$$

where

$$F(x,T) = Z \cdot \exp[-\delta E(x)/T] \quad (38)$$

$\delta E(x)$ is the energy gap of the coherent state as a function of the distance x from the CD center and Z is the partition function [30,35] given, in this case, by

$$Z = (N/V)(m \cdot T/2\pi)^{1/2}(k^2/2\pi) \cdot \exp(-\delta_0/T) \quad (39)$$

where m is the mass of a water molecule and, in the case of water, $k \sim 5 \cdot 10^{-10}\,m$ and $\delta_0 \sim 400\,cm^{-1}$.

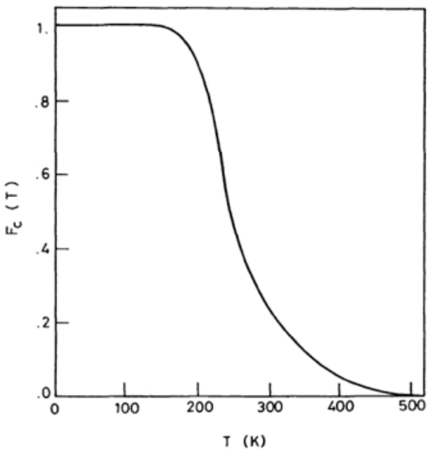

Fig. 3 behavior of coherent fraction in water [30,35]

The behavior of $F_{coh}(T)$ for bulk water is represented in the Fig. 3, from which we deduce that, for a temperature of about $T \sim 310\,K$ corresponding to the average temperature inside brain MT, we should have a coherent fraction $F_{coh}(T_{brain}) \sim 0.2$ that is approximately less than a half of the corresponding coherent fraction at room temperature. Nevertheless for the water enclosed within a cavity, as happens in MTs, it has been shown [39] that cavity wall is able to decrease the impact of thermal fluctuations so making the interfacial water substantially thermally isolated and then much more coherent than bulk water.

Since practically all the water contained in a living organisms is always very near to a “wall” [39] (typically less than a fraction of micron from a surface like a membrane or a molecular backbone) we can consider this water as interfacial water and then, for the above considerations, we can assume $F_c \to 1$.

A further confirmation of this assumption results from the experimental evidence that water inside cells resides in a sort of “glassy” state [40] whose coherent general properties has been already investigated [41] showing that, for this water, the coherent fraction is the same of that occurring for $T < 220\,K$ namely, from the Fig. 3, $F_c \sim 1$ able to guarantee the existence and the permanence of an almost fully-coherent state of water inside brain MTs.

In this way we have shown that also the question of environmental decoherence, properly raised by Mavromatos et al [26], can be issued within the framework of QED coherence in water, when we consider the coupling between electromagnetic and matter field occurring at the level of electronic energy transitions.

IV. Possibility of Hypercomputation in Brain MT by Means of Superluminal Photons

Feynmann defined the required energy per step for the computation process given by [42]

$$energy\ per\ step = 2k_B T(f-b)/(f+b) \quad (40)$$

where k_B is Boltzmann’s constant, T is a temperature, f is a forward rate of computation and b is backward rate.

Supposing there is no energy supply and parameters f and b are fixed during the computation, we can consider the infinite computational steps given by

$$E_1 = kE_0, E_2 = kE_1, \dots, E_n = kE_{n+1}, \dots \quad (41)$$

where we let the initial energy of computation be $E_0 = k_B T$, $k = 2(f-b)/(f+b)$ and E_n is the energy for the n-th step computation.

From the above we have $E_n = k^n E_0$, and then the energy loss for each computational step becomes

$$\begin{aligned} \Delta E_1 &= E_0 - E_1 = (1-k)E_0 \\ \Delta E_2 &= E_1 - E_2 = (1-k)kE_0 \\ &\vdots \\ \Delta E_n &= E_{n-1} - E_n = (1-k)k^{n-1}E_0 \end{aligned} \quad (42)$$

According to the paper by S. Lloyd [43], it is required for the quantum system with average energy ΔE to take time at least Δt to evolve to an orthogonal state given by

$$\Delta t = \pi\hbar/2\Delta E \quad (43)$$

from which, the total energy for the infinite steps yields E_0 if setting $E = \Delta E_i$ into (43), then the total time for the computation with infinite steps becomes

$$T = \sum_{n=1}^{\infty} \Delta t_n = (\pi\hbar/2E_0)\sum_{n=1}^{\infty} 1/(1-k)k^{n-1} \quad (44)$$

As the infinite sum of (44) diverges to infinity when satisfying $0 < k < 1$, the Feynman model of computation requires infinite time to complete the calculation.

Hence an accelerated Turing machine cannot be realized for computers utilizing ordinary particles due to the uncertainty principle. Recami claimed in his paper [20] that tunneling photons which travel in evanescent mode can move with superluminal group speed inside the barrier.

From the relativistic equation of energy and momentum of the moving particle, given by

$$E = m_0 c^2 \Big/ \sqrt{1-\left(v/c\right)^2} \tag{45}$$

and

$$p = m_0 v \Big/ \sqrt{1-\left(v/c\right)^2} \tag{46}$$

the relation between energy and momentum can be shown as $p/v = E/c^2$.

From (46), we have [44]

$$\left(v\Delta p - p\Delta v\right)\Big/ v^2 = \Delta E \big/ c^2 \tag{47}$$

Supposing that the approximation $\Delta v / v^2 \approx 0$ holds, the (47) can be simplified as

$$\Delta p \approx \left(v/c^2\right)\Delta E \tag{48}$$

This relation is also valid for the superluminal particle (which has an imaginary mass $i \cdot m_0$), the energy and the momentum of which are given by following equations, respectively

$$E = m_0 c^2 \Big/ \sqrt{\left(v/c\right)^2 - 1} \tag{49}$$

$$p = m_0 v \Big/ \sqrt{\left(v/c\right)^2 - 1} \tag{50}$$

According to the paper by M.Park and Y.Park [45], the uncertainty relation for the superluminal particle can be given by

$$\Delta p \cdot \Delta t \approx \hbar \big/ \left(v - v'\right) \tag{51}$$

where v and v' are the velocities of a superluminal particle after and before the measurement. By substituting (48) into (51), we obtain the uncertainty relation for superluminal particles given by

$$\Delta E \cdot \Delta t \approx \hbar \big/ \beta(\beta - 1) \tag{52}$$

when we let $v' = c$ and $\beta = v / c$.

Instead of subluminal particles including photons, the time required for the quantum system utilizing superluminal particles becomes [46]

$$\begin{aligned} T &= \sum_{n=1}^{\infty} \Delta t_i = \\ &= \left(\pi\hbar / 2E_0\right) \sum_{n=1}^{\infty} 1 \big/ \beta_n \left(\beta_n - 1\right)\left(1-k\right) k^{n-1} \end{aligned} \tag{53}$$

from the uncertainty principle for superluminal particles given by (52), where β can be given by

$$\beta_n = \sqrt{1 + m_0^2 c^4 \big/ E_n^2} = \sqrt{1 + m_0^2 c^4 \big/ k^{2n} E_0^2} \tag{54}$$

which is derived from (50).

From (53) and (54), it is seen that the computation time can be accelerated as shown in Fig. 4.

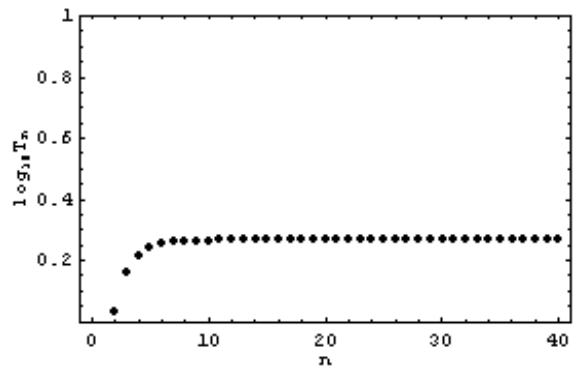

Fig. 4 time required to conduct computation at each step by using superluminal particles (for the case, $k = 1/2$ and $\gamma = 1.0$).

By the numerical calculation, it can be shown that the infinite sum of (53) converges to a certain value satisfying $0 < k < 1$, as shown in Fig. 5.

In this figure, the horizontal axis is for the parameter $\gamma = m_0 c^2 / E_0$ while the vertical one is for the time to complete infinite step calculations. This result means that infinite steps of computation can be conducted within a finite length of time by using superluminal particles.

From these calculation results, it can be seen that a hypercomputing machine can be realized by utilizing superluminal particles, instead of subluminal particles, for the Feynman's computational model.

Thus, contrary to the conclusion obtained relatively to the Feynman's model of computation when using ordinary particles, it can be seen that superluminal particles permits the realization of an accelerated Turing machine.

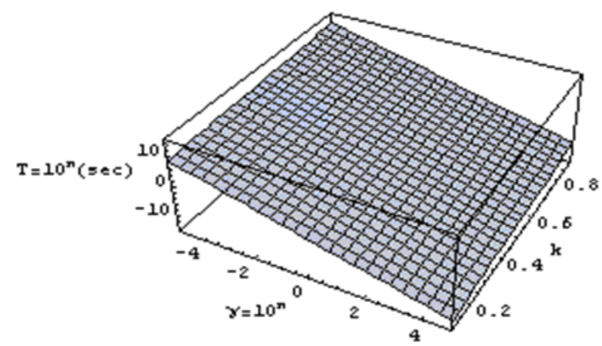

Fig. 5 computational required time for the superluminal particles.

It is known that an accelerate Turing machines allow us to be computed some functions which are not Turing-computable, such as the halting problem [47], described as "given a description of an arbitrary computer program, decide whether the program finishes running or continues to run forever".

Thus superluminal photons inside the microtubule permit us to conduct hypercomputation which cannot be realized by the conventional silicon processors.

V. Brain microtubules as waveguides and the amplification of superradiant evanescent waves

The frequency rescaling of superrandiant photons inside the water CD of brain microtubules determines, as we have seen, the "trapping" of the coherent e.m. field inside the CDs. Furthermore, the estimate of the radius of a single CD, supposed as spherically symmetric, given by (35) for the electronic transition $\omega_0 = 12.06\,eV$, allows us to interpret the inner hollow cavity of a MT as "filled" by such CDs, since its value is practically comparable with that of the circular cross section of a MT ($\sim 2.5 \cdot 10^{-8}\,m$) and less than a tenth of its average length ($\sim 10^{-6}\,m$). Now, by remembering each CD is the seat of a coherent e.m. field "confined" within its neighborhood, this suggests the idea that the whole inner cavity of MT could be just considered as a waveguide for such electromagnetic fields. In particular let's consider a rectangular shaped waveguide with length $L = a$ and width $W = b$ and consider the propagation of an e.m. wave along the z -axis.

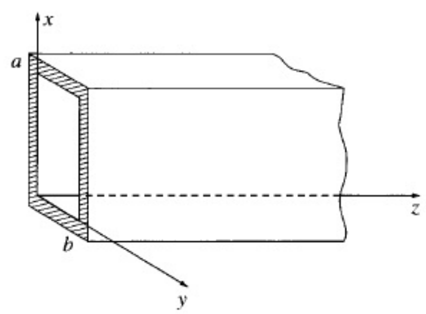

Fig. 6 schematic representation of an electromagnetic waveguide.

In particular we are looking for solutions of the Maxwell's equations in the form of TE waves (the case of TM waves is quite similar, while the case of TEM is trivial). It is well-known from the general theory that, when imposing the suitable boundary conditions at the inner waveguide surface

$$\begin{cases} E_{\parallel} = 0 \\ B_{\perp} = 0 \end{cases} \tag{55}$$

where $E_{\parallel}$ and $B_{\perp}$ respectively are the components of electric and magnetic fields parallel and orthogonal to the inner surface of the waveguide we can consider solutions in the form

$$B_z(x,y) = F(x)G(y) \tag{56}$$

where B_z is the z-component of magnetic field along the waveguide and F and G are twice differentiable generic functions. The resulting solution of Maxwell's equations inside the waveguide with the boundary conditions (55) of the type (56) are given by

$$B_z(x,y) = B_0 \cos(m\pi x/a)\cos(n\pi y/b) \tag{57}$$

with $m,n = 0,1,2,...$ and $B_0 = B_z(0,0)$, and is called the TE_{mn} mode. The corresponding wave number $|\vec{k}|$ is then

$$k = (1/c)\sqrt{\omega^2 - \omega_{mn}^2} \tag{58}$$

where

$$\omega_{mn} = c\pi\sqrt{(m/a)^2 + (n/b)^2} \tag{59}$$

is the *cutoff frequency* whose minimum value, for a given waveguide, is given by

$$\omega_{10} = c\pi/d \tag{60}$$

where $d = \max\{L,W\}$ and, in the case of a circular cross section, we can assume $d = 2r$, where r is the cavity radius.

The (58) can be also rewritten as

$$k = \omega_{eff}/c \tag{61}$$

with $\omega_{eff} \equiv \sqrt{\omega^2 - \omega_{mn}^2}$. This means the frequency of the e,m, wave propagating inside waveguide is smaller than its corresponding value in free space, being always $\omega_{eff} < \omega$. If we now recall the (29) we see it is just what happens within a CD in which in fact we have $\omega_{coh} \ll \omega_0$, so preventing the "release" of the coherent electromagnetic energy towards the outside of a CD. This means that, in the inner hollow of brain MT, the coherent e.m. field generated in water behaves as it would be "confined" in a e.m. waveguide or cavity and it is characterized by a photon frequency $\omega_{eff} = \omega_{coh}$. This consideration needs nevertheless further care.

In fact we see from (58) that, if $\omega < \omega_{mn} \equiv \omega_c$, the wave vector is imaginary: this means that no wave propagates within the waveguide but we can only have an evanescent e.m. field and we say that the wave guide is in cutoff. More specifically, being ω_{10} the smallest value of ω_{mn}, a sufficient condition for a waveguide to be in cutoff is obviously $\omega < \omega_{10}$. For a water CD associated to the considered electron transition we have seen that $\omega_{coh} \sim 10^{-2}\omega_0 = 0.1206\,eV$ while, from (60) and considering $r = R_{in}$, where $R_{in} \approx 17\,nm$ is the inner radius of MT, then we have

$$\omega_{10,MT} \simeq 2.770 \cdot 10^{16}\,Hz \tag{62}$$

while

$$\omega_{coh} \simeq 1.832 \cdot 10^{14}\,Hz \tag{63}$$

so showing that

$$\omega_{coh} \ll \omega_{10,MT} \tag{64}$$

meaning that the MT "waveguide" is always in cutoff regime with reference to the coherent e.m. field generated in water molecules, so at a first sight preventing any type of wave propagation along MT structure and beyond.

Nevertheless it has been shown [29] that a near-perfect tunnelling and amplification of evanescent e.m. field, as that associated to CD structure, is theoretically possible and experimentally proven in a waveguide even in a cutoff regime, provided that it is partially filled with a MTM. In this case the amplification and the tunnelling of an evanescent e.m. wave outside the waveguide is possible when

$$\omega < \omega_c = (\pi/a)/\sqrt{\varepsilon\mu_0} \tag{65}$$

where a is the waveguide width, ε and μ_0 respectively the dielectric permittivity of the MTM and the magnetic permittivity of vacuum. In this way, it would be sufficient to use an MTM with $\varepsilon > \varepsilon_0$ in order to allow the amplification and tunnelling of the evanescent e.m. field into "free" space.

Under these conditions it has been calculated [29] a possible amplification of the tunnelled evanescent wave up to over four times the original field amplitude after the interaction with the MTM-filled portion of the waveguide.

With reference to our system, the above possibility is then related to a value of MTM ε such that

$$\omega_{coh} < \omega_c(\varepsilon) \tag{66}$$

that would be in principle possible if we suppose the MT as having a structure similar to that of a suitable MTM as we'll see in the following section.

VI. Microtubules as "natural" metamaterials

The above model of MT as a waveguide allows us to derive a refraction index for it in the usual way as

$$n = ck/\omega \tag{67}$$

that, using the (58), can be written as

$$n(\omega) = \sqrt{1 - (\omega_{mn}/\omega)^2} \tag{68}$$

in our case, assuming $\omega_{mn} = \omega_{10}$ and using $\omega = \omega_{coh}$ we have

$$n^2(\omega_{coh}) = 1 - (\omega_{10}/\omega_{coh})^2 < 0 \tag{69}$$

giving an imaginary refraction index. An imaginary value of refraction index is a typical feature of well-known categories of MTMs as, for example, plasmas or ferromagnetic materials.

As we have previously seen the MTs are formed by the polymerization of a dimer of two globular proteins, α and β tubulin, whose the schematic "unrolled" view is shown in Fig.7.

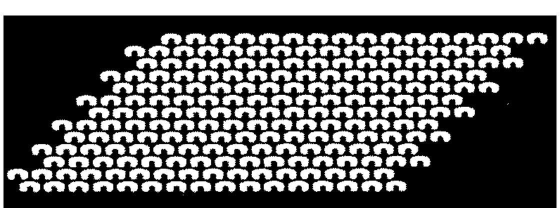

Fig. 7 schematic representation of MTs (unrolled) [48]

As the positive and the negative charges on the dimmers caused them align as shown in Fig.7, MT has a structure as natural metamaterial. From the shape of the tubulin, we can model each tublin as the split-ring resonator (SRR) consisted of a capacitance and an inductance electrically shown in Fig.8.

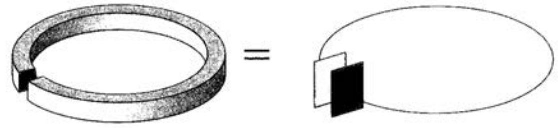

Fig.8 Model for the tublin protein by SRR

MTM consists of a periodic structure with the period being small compared to the optical wavelength and it affects electromagnetic waves by having structural features smaller than the wavelength of the respective electromagnetic wave.

When photon impinges such a structure composed of nano-resonators, it can excite electromagnetic oscillations.

They are particularly strong for frequencies near the resonance frequency shown as

$$f_{LC} = 1/2\pi\sqrt{LC} \tag{70}$$

where L is an inductance for a split-ring structure and C is its capacitance.

The most interesting optical effects may occur somewhat above or below the resonance. This can create a negative permeability and hence it can be seen from the following relation between k, ε_r and μ_r

$$k^2 = \varepsilon_r\mu_r\,\omega^2/c^2 \tag{71}$$

where ε_r and μ_r respectively indicate the relative electric and magnetic permittivity, that the wave number inside MT becomes imaginary which can produce evanescent wave enhancement.

B-I.Popa and S.A. Cummer confirmed the evanescent wave enhancement inside passive MTMs [49] by their experiment. R.W. Ziolkowski also predicted superluminal transmission of information through the electromagnetic MTM [50] without a violation of causality and we can conclude that the MT can propagate evanescent photons inside it by its natural MTM structure.

VII. Conclusions

In this paper we have shown, basing on the theoretical framework of QED coherence in condensed matter, that water contained inside the hollow volume of brain microtubules is able to exhibits a spontaneous superradiant quantum phase transition toward a energetically favored state, in which the electronic clouds of water molecules coherently oscillate in tune with a self-trapped electromagnetic field within defined space regions (coherent domains).

Differently from the models of quantum optical coherence in cytoskeletal MT proposed so far (that considers the energetic transitions of water molecules associated to rotational energy levels of the order of few meV), the picture here discussed assume the coherent system (water + electromagnetic field) to oscillate in phase with the electronic transition of water from the ground state to the level at energy $E = 12.06\,eV$, implying the supperradiant photons, generated inside the coherence domains, to have a wavelength much smaller than the length of a moderately sized MT in brain.

Furthermore, the coherent electromagnetic field arising from quantum vacuum oscillating in tune with water molecules is characterized by a negative squared mass of the superradiant photons (since they are trapped inside the coherence domain) and by an "evanescent" tail extending outside the coherence domain itself. In particular, these two latter features allows us to interpret these photons as superluminal evanescent (tunneling) photons that, as it has been shown in this paper, can be used by living system to implement high performance quantum computing inside brain using microtubules substrate as storage material.

The proposed model also overcomes some of the most important issues (as, in first place, the too long wavelength of superradiant photon with respect MT size and the too short environmental decoherence time) properly raised by some authors about the actual possibility to consider the superrandiant photons, generated inside MT from water coherent phase transition, in order to explain the occurrence of "ordinary" functions performed by brain as well as its eventual quantum hypercomputing capabilities.

It has been also shown the features of coherent e.m. field generated in water inside MTs allow us to interpret them as waveguides for such field that, however, being intrinsically evanescent, would be, at a first sight, not much usable in order to transmit information outside the MTs themselves.

Nevertheless, the theoretical and experimental possibility to generate a near-perfect tunneling and amplification of an evanescent e.m. field in a waveguide partially filled with a MTM and some interesting discussed analogies (both of e.m. and structural nature), between MTs and MTMs made we able to propose the idea to interpret the inner medium of the brain microtubules cylinder as having the properties similar to those characterizing metamaterials and so able to specifically allow and enhance the propagation of evanescent photons inside the neurons.

Obviously, further researches are needed in order to fully understand the above mechanisms and, to this aim, different further aspects of coherent interaction between microtubule structures and water they contain and their implications on brain capabilities, functions and processes as, for example, consciousness, will be analyzed in forthcoming publications.

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