TGD View of Microtubules as Quantum Systems

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Abstract

Around 2014, the latest hot news in quantum biology was the observation by the group led by Anirban Bandyopadhyay about detection of quantum vibration in microtubule scale - their lengths vary up to 50 μm. If this observation can be replicated, one can speak about breakthrough in quantum consciousness.

The findings reported in an earlier talk of Bandyopadhyay give support for the general TGD inspired view about topological quantum computation (TQC) and allow for a rather detailed model in the case of microtubules. The idea is that flux tubes form a 2-D coordinate grid consisting of parallel flux tubes in two different directions. Crossing points would be associated with tubulins and the conformational state of tubulin could define a bit coding whether the braid strands defining coordinate lines are braided or not (swap or not). In this manner any bit pattern at microtubule defines a particular TQC program. If also conformations are quantum superposed, one would have "quantum-quantum computation". It however seems that conformation change is irreversible chemical reaction so that this option is not feasible.

The TGD inspired modification of the proposal in terms of flux tube coordinate grids making possible TQC architectures with tubulin dimers defining bits defining in turn TQC program looks rather natural. Coordinate grids can be fixed on basis of the experimental findings and there are 8 of them. The interpretation is in terms of different resolutions. The grids for A and B type lattices are related by 2π twist for the second end of the basic 13-unit for microtubule. An attractive interpretation for the resonance frequencies is in terms of phase transitions between A and B type lattices. If A type lattices can be generated only

in phase transitions induced by AC stimulus at resonance frequencies, one could understand their experimental absence, which is a strong objection against Penrose-Hameroff model.

TGD suggests also a generalization of the very notion of TQC to 2-braid TQC with 2-D string world sheets becoming knotted in 4-D space-time. Now qubits (or their generalizations) could correspond to states of flux tubes defining braid strands as Penrose and Hameroff seem to suggest and the emergence of MTs could be seen as an evolutionary leap due to the emergence of a new abstraction level in cognitive processing.

About 10 years later (2024), Babcock et al reported of the evidence for a mesoscale quantum coherents consisting of microtubules, and this finding seems to be taken rather seriously also by the mainstream. During these 10 years, the TGD inspired quantum biology has developed considerably and in this article I combine the recent TGD based view of the findings of Bandyopadhyay and of Babcock et al.

1 Introduction

This article was written around 2014 but at the end of the article there is an addition about the discovery published 2024 that living matter (microtubules) seems to allow quantum coherence in mesoscales.

Around 2014, the latest hot news in quantum biology was the claim about corroboration of the Penrose Hameroff Orch OR theory (`http://www.kurzweilai.net/discovery-of-quantum-vibrations-in-micr`) [J1]. In my humble opinion the news suffers from rather heavy hyping. If the observation by the group led by Anirban Bandyopadhyay about detection of quantum vibrations in microtubule scale (their lengths vary up to 50 μm) can be replicated ,and one can speak about a breakthrough in quantum consciousness. However, the results do not prove Orch OR, which involves poorly defined vision about quantum gravitational description of state function reduction, so that most predictions are just order of magnitude estimates relying on Uncertainty Principle.

The biological half of the theory relies on microtubules and for this side of the theory the claimed finding would of course be a victory. Indeed, there is a meeting in Amsterdam devoted to Orch OR theory of consciousness motivated by this finding (`http://www.brakkegrond.nl/programma/1253/Penrose_Bandyopadhyay_Hameroff/Lezing_Microtubuli_het_grote_debat_over_het_bewustzijn/#eng`). Unfortunately, I could not find any article about the findings of Bandyopadhyay online. I managed however to find two years old Youtube talk of Bandyopadhyay summarizing earlier experimental results supporting the vision about microtubules as macroscopic quantum systems (`https://www.youtube.com/watch?v=VQngptkPYE8`) [J3] to be discussed below. The talk describes in informal manner results, most of which can be found also in the articles [J10, J11, J13].

The findings reported in the talk give support for the general TGD inspired view about TQC and allow a rather detailed model in the case of microtubules. The idea is that flux tubes form a 2-D coordinate grid consisting of parallel flux tubes in two different directions: the guess that they could consist of helical Fibonacci flux tubes and their mirror images is not however convincing. Crossing points would be associated with tubulins and the conformational state of tubulin could define a bit coding whether the braid strands defining coordinate lines are braided or not (swap or not). In this manner any bit pattern at microtubule defines a particular TQC program. If also conformations are quantum superposed, one has "quantum-quantum computation" . It however seems that conformation change is irreversible chemical reaction [J8] so that this option is not feasible.

The TGD inspired modification of the proposal in terms of flux tube coordinate grids making possible TQC architectures with tubulin dimers defining bits defining in turn TQC program looks more plausible to me. Coordinate grids can be fixed on the basis of the experimental findings and there are 8 of them. The interpretation is in terms of different resolutions. The grids for A and B type lattices are related by 2π twist for the second end of the basic 13-unit for the microtubule. An attractive interpretation for the resonance frequencies is in terms of phase transitions between A and B type lattices. If A type lattices can be generated only in phase transitions induced by AC stimulus at resonance frequencies, one could understand their experimental absence, which isa strong objection against the Penrose-Hameroff model.

This would fit very nicely with the general vision about frequencies as passwords inducing not only directed attention but activities in target - also TQCs! The increase of Planck constant could be associated with the phase transition to A-phase making possible high T_c dark super-

conductivity for which evidence is observed! One can even deduce estimates for $h_{eff}/h = n$ if one requires that AC photons have energy above thermal threshold: $n = h_eff/h = f_{visible}/f_AC$ would be the estimate. For biophoton energies one would obtain something like $n \simeq 10^8 - 10^9$, which pops up in different contexts in the TGD framework.

This picture generalizes in the fractal universe of TGD. One can form layers of 2-D coordinate grids and connect them by vertical flux tubes to obtain 3-D grid defining TQC. The brain is known to have grid-like architecture and neurons could by quantum computation produce bit/qubit-defining swap or not/superposition of swap and not-swap for a larger scale TQC. One would have fractals of TQCs. One can even think 4-D grids in the Euclidean spacetime regions (predicted in TGD Universe) with 6 bits defining the swaps at each crossing point: could this have something to do with the genetic code?

A further idea is that 1-braid TQC generalizes in a natural manner to 2-braid TQC in the TGD framework (for 2-braids see [K5]). The knotting occurs for string world sheets defining the orbits of braid strands - say magnetic flux tubes idealized to strings. In the case of microtubules this option suggests itself strongly. The emergence of MTs could have meant emergence of 2-braid TQC and the increase of abstraction level in the information processing. Note that 2-braiding is possible only if string worlds sheets "live" in 4-D space-time: for superstrings "living" in higher-D space-time this is not possible.

About 10 years later (2024), Babcock et al [**?**] reported on the evidence for a mesoscale quantum coherents consisting of microtubules, and this finding seems to be taken rather seriously also by the mainstream. During these 10 years, the TGD inspired quantum biology has developed considerably [L3, L4, L6] and in this article I combine the recent TGD based view of the findings of Bandyopadhyay and of Babcock et al.

2 Theoretical ideas

The theoretical ideas of three models relevant to the experiments of Bandyopadhyay will be discussed first. The theories are the Penrose-Hameroff theory, Bandyopahdyay's theory and TGD as it was for a decade ago.

2.1 Penrose-Hameroff theory

Approximately two decades ago Penrose and Hameroff proposed a model that they called Orchestrated Objective Reduction (Orch OR) [J17]. Besides the highly speculative quantum gravity related ideas, the model assumes that microtubules are quantum coherent systems essential for consciousness. For the importance of microtubules one can find a lot of qualitative support. A I believe that microtubules are important for consciousness and I have developed ideas about the role of microtubules [K7]. Personally, however, I find it difficult to believe in the reduction of consciousness to microtubular level, but see microtubules as one particular layer in the hierarchy of conscious entities. Personally, I would prefer fractality over the naive length scale reductionism.

Many objections [J8] against the biological feasibility of Orch OR (`http://en.wikipedia.org/wiki/Orchestrated_objective_reduction`) [J17] have been raised. For the latest response of the authors to the criticism see [J16]. There are two basic challenges: one should formulate precisely what Orch OR really means and be able to identify the qubit.

1. The basic vision about quantum superposition of space-time geometries gives rise to consciousness as something analogous to quantum computation. State function reduction would thus reduce to a mechanism rather than being something irreducible. Most quantum physicists would disagree about this. The quantum superposed geometries would be protein conformations. Since there is no theory of quantum gravity, the proposal boils down to the ad hoc estimate for the time τ for Orch OR to take place claimed to be $\tau = \hbar/E_G$, where E_G is the difference of gravitational energies for the superposed geometries. The estimates favor nuclear scale 5 fm and one needs a coupling between nano-scale physics of electrons and physics nuclei and London forces are suggested to be responsible for this coupling. It deserved to be mentioned that the gravitational energy for a blog of water with radius around 10^{-4} meters - the size scale of a large neuron - is about Planck mass so that gravitation and biology might relate. In my own proposal involving large gravitational Planck constant

assigned to space-time sheets mediating gravitational interaction, Planck mass might serve as a threshold above which large values of Planck constant would emerge [K11, K8].

2. Concerning the identification of qubit there is a long list of suggestions. The superposition of tubulin conformations was one of the first proposals. Reimers [J8], who has criticized heavily Orch-OR proposal, reports that irreversible chemical reaction is responsible for selecting conformation so that quantum superpositions would not make sense. Conformational switching could however be involved with classical computational aspects of biological information processing and Hameroff has proposed before Orch OR that microtubules could act as classical cellular automatons.

   Also other proposals for qubit have been made. Quantum fluctuations generating London force between electric dipoles could somehow give rise to qubits. Also magnetic dipoles, nuclear spin, AC current flow, and synergistic modes have been mentioned. Also the identification of qubit as a helical conduction pathway has been proposed ("Oscillating London force dipoles in resonance rings in helical pathways through microtubule lattices"). It is difficult to imagine what the two superposed states defining qubit would be. For instance, could qubit correspond to electron current running in two different directions and is quantum superposition possible at criticality for a phase transition inducing the change of the current direction? For this option the information storage capacity of microtubule would be rather modest. In also difficult to see the claimed connection with topological quantum computation since braiding gives rise to entanglement between states at the ends of the braids.

Orch OR proposal involves several interesting ideas probably relevant for quantum consciousness.

1. Aromatic rings have probably some deep role in quantum consciousness. For instance, most psychoactive biomolecules and also DNA and three amino acids contain them. Hameroff and Penrose trace this role to the London force between aromatic rings and quantum fluctuations making them qubits. I am unable to imagine what the exact proposal is. In any case, what is known is that electrons at aromatic rings are delocalized.

   Comment: My own humble proposal is that electrons could be further delocalised at magnetic flux tubes in longer scales and make cyclotron BE condensates of dark electrons or their Cooper pairs possible. They would make possible the coupling between receptor-information molecule complexes and magnetic bodies at various levels of hierarchy. Hierarchy of Planck constants and negentropic entanglement suggests the existence of a new kind of state consisting of electrons (that is fermions) but analogous to Bose-Einstein condensate.

2. The idea about insulation provided by hydrophobic pockets of proteins against fluctuations destroying quantum coherence is nice and it would be natural to put aromatic rings into these pockets.

3. The needed long value of Orch OR decoherence time τ (originally assumed to correspond to 40 Hz thalamocortical resonance frequency) is one of the problems of Orc OR and the recent discovery of EEG like oscillations in kHz range [J12] is claimed to make the situation more tolerable.

   Comment: Fractal hierarchy of EEGs mediating communications between parts of biological body and corresponding magnetic body is basic prediction of TGD and the observation seems to provide evidence for this prediction.

4. Reimers et al challenges [J9] also Fröhlic Bose-Einstein condensation [J15] and claims that according to his own simulations the resulting state is extremely incoherent [J9]. There are however models which give Bose-Einstein condensation [J2] and the in [J3] the experimental findings about assembly of microtubules are interpreted as Fröhlic condensation. The frequency inducing the condensation would be however 3 orders of magnitude lower than predicted by Fröhlich.

There is a further puzzling result (`http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2114131/pdf/jc10231067.pdf`) [J7] in conflict with the assumption of Orch OR that brain microtubules are

dominantly so-called A-type tubules. Brain microtubules are re-assembled in vitro form lattices of type B and for them the lattice must have surface discontinuities. This makes sense for microtubules which are partially fused together as in the structures consisting of cylinder whose surface is formed by 9 units consisting of 3 microtubules glued together along their sides. This would not allow Fibonacci helices proposed by Penrose and Hameroff to serve as conducting pathways defining the analogs of braid strands in their model for microtubule as a topological quantum computer (TQC) unless one is ready to give up helical symmetry. One way out of the difficulty would be that vitro results do not hold in vivo but Kikkawa et al has shown that all in vivo microtubules have lattice of type B (`http://jcb.rupress.org/content/127/6/1965.abstract`) [J6].

The above mentioned article concludes that only the lattice B is realized in nature. This lattice does not possess helical symmetry. After each full turn along sequence α or β tubulin sequence there is a shift as the figure 2 of the article demonstrates: this discontinuity is called seam in the article. Furthermore, these helices can be said to have periodicity 5. The helix-like curve satisfies the condition $z = 4a\phi/2\pi$ and the n^{th} tubulins along the vertical are located at $z(n) = na$, a the size of the tubulin. For $\phi = 2\pi$ one has $\Delta z = a$ rather $\Delta z = 0$ as figure 2 of the article shows. This discontinuity could have some important biological meaning.

Hameroff, Nip, Porter, and Tuszynski have an article about microtubules as topological quantum computation written in 2002 [J5]. They do not give any justification for why the conduction pathways should correspond to Fibonacci numbers but the article by Hameroff represents evidence that the important certain amino-acids crucial for consciousness inside tubulin molecules are located along the Fibonacci conduction pathways (`http://www.quantumconsciousness.org/biosystemselsevier.htm`) [J5].

2011 Hameroff and Penrose considered the possibility that microtubules could perform topological quantum computation. The proposal of Penrose and Hameroff (`http://www.quantumconsciousness.org/biosystemselsevier.htm`) [J5] assumes realization of braiding in terms of helical braids strands assignable to A-type microtubules (which according to experimeters do not exist in brain and - as it seems - in living matter in general). In the simplest realization the strands are parallel to each other and have horizontal periodicity characterized by 13 tubules. Also Fibonacci pathways with horizontal periodicity of 3, 5, and 8 are Fibonacci pathways. The strands with different periodicities can intersect and can therefore be braided. One can also construct left- and right handed variants of the strands and left- and right-handed strands intersect periodically with a period of 13. The experiments discussed in bneumtvideo however suggest a different kind of braidings.

In the intersection points braiding (swap) operation could be realized meaning that the first strand goes either over or below the second one. Gupta and Hameroff suggests that MAPs are responsible for this kind of swap and thus define the fundamental quantum gates for TQC (`https://sbs.arizona.edu/project/consciousness/report_poster_detail.php?abs=1435`) [J14]. Of course, also more complex gates can be imagined but swap is enough to build universal TQC. Official biology assigns to MAP many other functions associated with MAPs but also this function can be imagined. Penrose and Hameroff have also consider the possibility that topological qubits are represented in terms of quantum superpositions of helical pathways with 13-periodicity characterized by the gap between neighboring pathways.

2.2 The identification of Bandyopadhyay for conduction pathways

In his Youtube talk Anirban Bandyopadhyay (`https://www.youtube.com/watch?v=VQngptkPYE8`) [J3] discussed an identification of conduction pathways different from that of Penrose and Hameroff. In [J13] Gosh, Sahu, and Bandyopadhyay argue for evidence for massive global synchronization in brain and claim that experimental findings support the Penrose-Hameroff theory. In the article "Atomic water channel controlling remarkable properties of a single brain microtubule: correlating single protein to its supramolecular assembly" [J10] it is reported that ordered water inside microtubule is necessary for the conduction inside microtubule. According to the same article the tubulins inside microtubules have the same energy levels in chemical energy range as isolated tubulins which suggests that the mechanism binding tubulins to form MT is not chemical. In the article "Multi-level memory-switching properties of a single brain microtubule" [J11] it is reported that the hysteresis curve for current along MT as a function of voltage is an ideal square curve meaning that there is no dissipation involved with the change of the current direction. This would make MT an ideal memory device. Whether Penrose/HAmeroff have in mind the use of current

direction as qubit remains unclear. In the video talk, Bandyopadhyay also refers to these results.

I consider only the general proposal discussed in the video lecture here: the Youtube representation gives concrete illustrations of conduction pathways.

1. It is assumed that there are two kinds of hexagonal tubulin lattices labelled as A and B. As found there is strong evidence that A-type tubules do not exist stably. For both types the tubulin dimers defining dipoles are nearly axial and define candidates for conduction paths with winding periodicity of 13 tubulin dimers. For B type one has rows made of α or β type tubulins along with α and β have an effective periodicity of five if one accepts discontinuity at after 2π rotation. One might think that this dictates the choice of the candidates for the conduction paths to consist of sequences of $\alpha - \beta$ dimers: for these sequences are along the microtubule. If hops occur between α and β this assumption is natural. The proposed pathways are however more general and - as it seems to me - based on rather an ad hoc mathematical rule.

2. The notion of helical conduction pathway is the starting point. For B-type tubules this notion must be modified. Presumably the criterion for what it is to be a helical pathway is that they are straight-lines connecting nearest neighbors to each other- this is natural if conduction is identified as hopping between neighboring tubulin molecules. The position of each pathway represented by a value of discrete dynamical variable replacing spin as representation of qubit -essentially the angle $\phi = n \times 2\pi/13$ is in question. There are 13 different values for ϕ. For A-type conducting pathways, the condition that one has a $\alpha - \beta$ sequence very probably gives the claimed pathways with periodicity 13. One can ask whether the pathways of type A are obtained by twisting the pathways of type B at the second end by 2π and whether living systems could be able to perform this twist to achieve phase transition between two states of the microtubule.

3. Instead of a single pathway one considers groups of parallel pathways consisting of translations of a fixed pathway with a fixed gap $\Delta\Phi_{gap} = n_{gap}2\pi/13$ along the circumference of the microtubule. I failed to understand the motivation for this: maybe the idea is that the additional degree of freedom makes possible the analog of spin degrees of freedom as the angular position of the pathway. One could also consider the possibility that the translations of a pathway define a braid: this braid would be however trivial since the pathways are parallel. If I have understood correctly, topological qubits would be represented as quantum superpositions of helical conduction pathways with the same gap $\Delta\phi = n_{gap} \times 2\pi/13$ between neighboring pathways. This is not what TGD suggests.

4. By $n = 13$ modulo arithmetics it can show that the series of pathways with $n = kn_{gap} \ \ mod \ \ 13$, $k = 1, 2, ...$ generates additional gaps. One says that the decomposition occurs. The addition of translated parallel pathways can also lead to a pair of pathways with $n_{gap} = 0$ or $n_{gap} = 1$ in which case pathways overlap or touch. This is not allowed. What this means physically is unclear to me. One could also avoid touching simply by allowing only the translates to be such that $kn_{gap} \leq 13$ holds true: even weaker condition can guarantee this.

3 The observations of the group of Anirban Bandyopadhyay from the TGD point of view

The observations of Anirban Bandyopadhyay are briefly summarized by Massimon Pregnolato at `http://www.quantumbionet.org/admin/files/MassimoPregnolato-RitaPizzi2011.pdf`. At this stage one can of course several models for the findings and in the following one option is selected.

1. The most plausible model is based on the notion of coordinate grid formed by longitudinal and transversal magnetic flux tubes whose crossing points are the points at which swap occurs or does not occur depending on the state of tubulin dimer. The grids associated with A and B tubules are obtained by a 2π twist for the upper end of the tubulin.

2. There are a large number of options for grids and they are identified on the basis of the experimental findings. Transversal coordinate lines would correspond to the 7-periodic

parallel lines with either gap 2 or 3 (gap 4 lines decompose to gap 4 and gap 2 lines) and longitudinal coordinate lines to one of 4 line groups involving four gaps so that 8 coordinate grids are obtained and related by a 2π twist for A and B tubules respectively. Gaps could characterize measurement resolution.

3. For A-type microtubule one can consider also Fibonacci grids constructed from helical curves and their mirror images with periodicities 3,5,8,13 and arbitrary gaps but it seems that it is difficult to interpreted the resonance frequencies and understand their number for this option.

3.1 Fröhlich B-E condensation or something else?

Excitation at the resonance frequencies causes microtubules to assemble extremely rapidly. This is proposed to be due to Fröhlich condensation. The resonance frequency of AC stimulation leading to a rapid generation of microtubules in the length scale range $[.2 - 22.5]$ μm is around 8 MHz. There is correlation between resonance frequencies and lengths of microtubules and qubit sets that are possible.

Comment: The identification as formation of Fröhlich B-E condensate can be criticized. The frequency at which this would take place was predicted by Fröhlich to be around GHz rather than in the MHz range.

In the TGD framework AC stimulation could generate a flux tube grid or activate an existing magnetic flux tube grid forming a braid-like structure serving as a template for the formation of microtubules around it. If the formation of the grid corresponds to quantum criticality, the resonance frequencies could also generate phase transitions between A and B type states of the microtubuli. AC signals could also generate contacts to these flux tubes making possible supra currents. The formation of microtubules is known to proceed by the formation of vertical nucleotide polymers which are then glued together horizontally: flux tubes could serve as a template for the formation of the nucleotide polymer. The magnetic fields at flux tubes can be accompanied by helical electric fields (in this case both magnetic and electric fields are helical) and these fields could be responsible for the polarization of microtubule and induce the growth of microtubules in such a manner that the polarized alpha-beta tubulin always attaches in the same manner to the growing polymer. Fröhlich condensation would be a consequence of generation of flux tube coordinate grids defining microtubule skeleton- growth of the magnetic body would precede that of biological body.

The length of the tubule increases with resonance frequency which suggests that a single tubulin dimer is added to the polymer during each cycle. MHz range and formation time around a few seconds. This would mean something like 10^6 giving MT with length of order 10^{-4} meters. The order of magnitude is correct.

3.2 8 resonance frequencies in AC stimulation and 8 distinct interference patterns

Microtubules are reported to have 8 resonance peaks for AC stimulation (kilohertz to 10 megahertz), which appear to correlate with various helical conductance pathways around the geometric microtubule lattice. The explanation is proposed in terms of current pathways which are identified as topological qubits.

Comment: To me this terminology looks strange and confusing. Why not speak about braid strands or specify what topological qubit means if one is speaking about TQC? I am unable to understand why groups of parallel pathways are considered as topological qubits (TQs). The idea about parallel translates might however make sense.

As already explained, the notion of coordinate grid in the sense discussed is consistent with the findings. The resonance frequencies could correspond to phase transitions changing A-type coordinate grids to B-type or vice versa. Coordinate grid would define the basic architecture of TQC.

The second claim is that there are altogether eight distinct quantum interference patterns from a single microtubule, each correlating with one of the 8 resonance frequencies and pathways.

According to the interpretation discussed in the talk 4 sets of four pathways representing quantum TQ each can exist simultaneously for type A microtubules claimed to be ideal for quantum computation. Lattices of type B exhibit 4 different pathways and are claimed to be ideal for communications. The lattices A and B are complementary in the sense that together they allow all possible pathways (this is not quite true: $n_{gap} = 12$ is lacking). The set of possible pathways depends on the length of MT.

Comment: Also this would conform with the TGD inspired model in which one has 8 coordinate grids for tubules of B and their deformations by twist to A type tubules. The 8 interference patterns would correspond to different coordinate grids. What coordinate grids are physically allowed coordinate grids depends on the length of the microtubule.

3.3 Observations about conductivity

There are also several observations about conductivity suggesting quantum coherence.

1. In assembled microtubules AC excitation at the resonant frequencies causes electronic conductance to become lossless, or 'ballistic', essentially quantum conductance, presumably along these helical quantum channels. Resonance in the range of kilohertz demonstrates microtubule decoherence times of at least 0.1 millisecond. Does this mean that AC signals at resonance frequencies are able to create these channels or groups of them?

   Or does this mean that the resonance signal transforms the microtubule to A (or B) type lattice which is highly conducting or even super-conducting (via magnetic flux tubes). The claim that A type lattice does not exist in vivo reduces to the statement that it does not exist stably in vivo. The AC signal at resonance frequency induces the twist taking lattice B into lattice A in which TQC is possible.

2. There are three frequency scales corresponding to kHz Hz, MHz and GHz ranges. The natural identification for these rather low frequency scales is in terms of cyclotron frequencies of dark electrons and possibly also various ions at magnetic flux tubes. The simplest identification would be in terms of three ranges for the strengths of magnetic field. I have proposed that .2 Gauss magnetic field define endogenous magnetic field explaining the effects of ELF em radiation on brain in terms of cyclotron transitions of biologically important ions, in particular Calcium ions for which cyclotron frequency would be 15 Hz (later an alternative explanation making essentially the same predictions has emerged). For electrons the cyclotron frequency would be .5 MHz so that for 16 times strong field would correspond to cyclotron frequency of 8 MHz appearing as resonance frequency. GHz frequency would require a magnetic field of .04 Tesla.

3. It is stated that the system cannot be classified as an insulator, semiconductor, or conductor. The reason would be that the two bands involved do not overlap as in conductors, are not completely separate with a large gap as in insulators, nor separate with a small gap. Instead the bands touch each other in a pointwise manner.

   Comment: Stimulus with the resonance frequency could regenerate the flux tubes or bridges to the flux tubes allowing the transfer of electrons to them. The ballistic resistance temperature independent resistance would be due to a very long free path or due to super-conductivity at the magnetic flux tubes - the latter is the TGD inspired hypothesis. This kind of behavior could result if the electrons can leak to the flux tube only if they have the same momentum as the Cooper Bose-Einstein condensate at the flux tube. Resonance condition would mean that the magnitude of the wave vector of electron is quantized in magnitude: this would also support the proposed interpretation.

4. It is claimed that conductance does not depend on microtubule length, is temperature independent, and has discrete values. Also ohmic dissipation is claimed to be negligible.

   Comment: The interpretation could be in terms of superconducting current pathways defined by magnetic flux tubes that looks natural as already found.

The observation that water is necessary for MT conductivity [J10] suggests that the presence of water is essential for large h_{eff}. One of the many possibilities is that the flux tubes (which are closed) return through the interior of MT containing the ordered water. Also dark variants of genes realized as dark proton sequences dark nuclei could be involved.

3.4 Ferroelectric hysteresis

What is interpreted as ferroelectric hysteresis is claimed to demonstrate memory capacity in microtubules [J11]. Current viz. voltage over the microtubule exhibits square hysteresis. Suddenly all-in one jump, changing the direction of current at critical voltage, occurs. This is analogous to ferromagnetic or ferroelectric behavior but in a completely quantal manner.

One can ask whether the quantum superpositions of two current directions might represent qubit. If so, the information processing capacity of microtubule would be rather modest unless one seriously considered 2-braid TQC (recall however that in neuroscience a single neuron is assumed to represent bit).

It is not at all obvious that ferroelectric hysteresis is in question and TGD suggests a different interpretation for the hysteresis curve. The current as function of voltage could reflect quantum coherent current in Bose-Einstein condensate of electronic Cooper pairs with all Cooper pairs having the same momentum. Macroscopic quantum coherence would make the state stable against perturbations defined by the external voltage and only when the voltage exceeds critical magnitude the state would change its momentum to opposite values instantaneously. If the interpretation as cyclotron BE-condensate is correct one would have Cooper pairs with spin 1 at the same state and effectively only a single particle representing memory.

The assumption of Bose-Einstein condensate might be unnecessarily strong: negentropic entanglement might be enough. Dark electrons are negentropically entangled and the entanglement stores potentially conscious information. The degeneracy of the ground state essential for achieving stable enough entanglement also in standard approach to TQC. The negentropic entanglement would not be in spin degrees of freedom but in those labeling sheets of the covering of M^4 and CP_2 defined by the space-time sheet of electron. Anti-symmetry in these exotic degrees of freedom would make electrons bosons if seen from the perspective of standard physics and allow them to effectively B-E condense to the same state with respect to standard quantum numbers. Note that this proposal resembles somewhat the proposal of Hameroff and Penrose for topological qubits in terms of parallel current pathways with the same gap. In this case the negentropic entanglement could perhaps stabilize the state in the sense that NMP [K6] would not allow the quantum jump leading to the opposite direction of electron current to take place.

3.5 Dynamical instability of MTs

MTs are dynamically unstable and the length of MT changes in jumps. The conjecture of the talk is that some kind of language is involved. On the basis of few second time scales one can wonder whether the correspondence with language production could be rather direct. Could regions of type A contain the information communicated in speech, say the information needed to form words or sentences? If microtubules of type B are indeed responsible for communications, one can ask whether $A \to B$ phase transitions generate the signal in turn inducing the nerve pulse patterns correlating with internal speech. The connection with language could be realized also at gene level [K2].

I have proposed that a microtubule acts as a quantum antenna [K7] emitting radiation with frequencies $f_n = nc/L$, where L is the length of MT. The variation of the length of microtubule would predict frequency modulation of the radiation coding for potentially conscious information. The model for nerve pulse and EEG makes similar prediction [K10, K1]. Josephson frequency for cell membrane as Josephson junction is proportional to membrane voltage and the variations of membrane voltages due to oscillations and nerve pulse activity are coded to EEG via frequency modulation. Even ordinary speech involves frequency modulation as is clear by listening recorded speech with abnormally slow speed. If microtubules talk, the most natural language would be based on frequency modulation.

The system seems to be critical, maybe it is quantum critical in the TGD sense. At quantum criticality the dynamics involves a large number of length scales. In TGD framework quantum criticality would mean that the hierarchy of Planck constants is involved such that given length scales is proportional to the effective value of Planck constant. Maybe different lengths for flux tubes correspond to values of effective Planck constant $h_{eff} = nh$.

4 Evidence for mesoscopic quantum coherence in living matter

This section has been added 10 years after writing the original version of the article. Penrose-Hameroff Orch-OR proposal [J17] for a theory of consciousness raises microtubules in a special role. In the TGD framework also MTs could represent an important level in the scale hierarchy but would not be the only key players in the functioning of living systems. The key problem of all quantum theories of consciousness is whether and how the brain and biosystems in general can allow quantum coherence in mesoscales.

In the standard quantum theory this looks extremely implausible. Quantum Sabine Hossenfelder how tells in her video (see this) about the recently observed evidence for quantum coherence in mesoscales by Babcock et al [I2].

4.1 Experimental evidence for the mesoscale quantum coherence of living matter from superradiance

The abstract to the article of Babcock et al summarizes the findings.

Networks of tryptophan (Trp) an aromatic amino acid with strong fluorescence response are ubiquitous in biological systems, forming diverse architectures in transmembrane proteins, cytoskeletal filaments, sub-neuronal elements, photoreceptor complexes, virion capsids, and other cellular structures.

We analyze the cooperative effects induced by ultraviolet (UV) excitation of several biologically relevant Trp mega-networks, thus giving insights into novel mechanisms for cellular signaling and control.

Our theoretical analysis in the single-excitation manifold predicts the formation of strongly superradiant states due to collective interactions among organized arrangements of up to $\geq 10^5$ Trp UV-excited transition dipoles in microtubule (MT) architectures, which leads to an enhancement of the fluorescence quantum yield (QY) that is confirmed by our experiments. We demonstrate the observed consequences of this superradiant behavior in the fluorescence QY for hierarchically organized tubulin structures, which increases in different geometric regimes at thermal equilibrium before saturation, highlighting the effect's persistence in the presence of disorder. Our work thus showcases the many orders of magnitude across which the brightest (hundreds of femtoseconds) and darkest (tens of seconds) states can coexist in these Trp lattices.

From the article it is clear that the observed phenomenon is expected to be very common and not only related to MTs. From Wikipedia one learns that tryptophan is an amino acid needed for normal growth in infants and for the production and maintenance of the body's proteins, muscles, enzymes, and neurotransmitters. Trp is an essential amino acid, which means that the body cannot produce it, so one must get it from the diet.

Tryptophan (Trp) is important throughout biology and forms lattice-like structures. From the article I learned that Trp plays an essential role in terms of communications. There is a connection between Trp and biophotons as well. Trp's response to UV radiation is particularly strong and also to radiation up to red wavelengths.

What is studied is the UV excitation of the Trp network in the case of MTs. The total number of Trp molecules involved varies up to 10^5. The scales studied are mesoscales: from the scale of a cell down to the scales of molecular machines. The wavelengths at which the response has been studied start at about 300 nm (4.1 eV, UV) and extend to 800 nm (1.55 eV, red light) and are significantly longer than tubulin's scale of 10 nm. This indicates that a network of this size scale is being activated. The range of time scales for the radiant states spans an enormous range.

UV excitation generates a superradiance meaning that the fluorescence is much more intense than it would be if the Trps were not a quantum-coherent system. The naive view is that the response is proportional to N^2 rather than N, where N is the number N of Trp molecules. Superradiance is possible even in thermal equilibrium, which does not fit the assumptions of standard quantum theory and suggests that quantum coherence does not take place at the level of the ordinary biomatter.

In standard quantum physics, the origin of the mesoscale coherence is difficult to understand. Quantum coherence would be the natural explanation but the value of Planck constant is far too

small and so are the quantum coherence lengths. The authors predict superradiance, but it is not clear what assumptions are involved. Is quantum coherence postulated or derived (very likely not).

4.2 The TGD based interpretation for the superradiance

I have considered MTs in several articles [L10] [K10, K7, K9]. In TGD, the rather obvious interpretation would be that the UV stimulus induces a sensory input communicated to the magnetic body (MB) of the Trp network: this signal is analogous to the EEG and in turn produces superradiance as a "motor reaction" of MB. The idea about MT as a quantum antenna is one of the oldest ideas of TGD inspired quantum biology [K7]. The communication would be based on dark photons involved also with the communications of cell membrane to the MB of the brain and with DNA to their MBs.

The Trp network could correspond to some kind of lattice structure or be associated with such a structure at the MB of the system. The notion of bioharmony [K3] [L1] leads to a model of these communications based on the universal realization of the genetic code in terms of icosa tetrahedral tessellation of 3-D hyperbolic space H^3 identifiable as light-cone proper time constant hyperboloid.

The icosa tetrahedral tessellation [L2, L5] is completely unique in that it has tetrahedrons, octahedrons, and icosahedrons as basic objects: usually only one platonic solid is possible. This tessellation predicts correctly the basic numbers of the genetic code and I have proposed that it could provide a realization of a universal genetic code not limited to mere biosystems. Could the cells of the Trp lattice correspond to the basic units of such a tessellation?

The work of Bandyopadhyay et al [J3, J13] (see also this) provides support for the hypothesis that there is hierarchy of frequency scales coming as powers of 10^3 (10 octaves for hearing in the case of humans) ranging from 1 Hz (cyclotron frequency of DNA) and extending to UV frequencies.

The hierarchy of field bodies could correspond to a hierarchy of MBs and electric field bodies (EBs). Gravitational MBs assignable to astrophysical objects [L3, L4] and EBs assignable to systems with long length scale electric fields [L6, L11] can be considered. They possess a very large value of the gravitational/electric Planck constant giving rise to a long length scale quantum coherence.

Gravitational MBs have a cyclotron energy spectrum, which by Equivalence Principle is independent of the mass of the charged particle. The discrete spectrum for the strengths of the endogenous magnetic field postulated by Blackman [J4] and identified as the non-Maxwellian monopole flux tube part of the magnetic field having minimal value of $2B_E/5 = .2$ Gauss would realize 12-note spectrum for the bioharmony [L1]. The spectrum of generalized Josephson energies assignable to the cell membrane depends only very weakly on h_{eff} whereas standard Josephson energy is independent of h_{eff} [L10].

Both cyclotron and Josephson frequency spectra are inversely proportional to the mass of the charged particle, which makes them ideal for communication between ordinary biomatter and dark matter. Frequency modulated signals from say cell membrane to the MB and coding the sensory input would propagate as dark Josephson photons to the MB and generate a sequence of resonance pulses as a reaction, which in turn can induce nerve pulses or something analogous to them in the ordinary biomatter [L12]. In a rough sense, this would be a transformation of analog to digital.

Authors also propose that superradiance could involve a shielding effect, analogous to what happens in the Earth's magnetic field and might be based on a similar mechanism.

1. In the standard description, the Earth's magnetic field catches the incoming cosmic rays, such as UV photons, to the field lines, and thus prevents the arrival of the radiation to the surface of Earth. Van del Allen radiation belts are of special importance.

2. In the TGD description, a considerable fraction of incoming high energy photons and maybe also other higher energy particles would be transformed to their dark variants at the magnetic monopole flux tubes of the MB of the Earth with a field strength estimated to be $B_{end} = 2B_E/5$, where $B_E = .5$ Gauss is the nominal value of the Earth's magnetic field. This mechanism would transform the high energy photons to low energy dark photons with much longer wavelengths which have very weak interactions with the ordinary biomatter. These in turn would be radiated away as ordinary photons and in this way become neutralized. The scaling factor for the wavelength would be $\hbar_{gr}/h$ if the gravitational MB of the Earth is involved.

Something similar would take place in biological systems at cellular level. The UV photons would be transformed to dark photons with much longer wavelengths and radiated away as ordinary photons.

Can one identify a range of biological scales perhaps labelled by the values of $\hbar_{eff}/h$ coming as powers of 10^3.

1. The findings of Cyril Smith [I1] related to the phenomenon of water memory suggest that in living matter a scaling of photon frequency can take place with a scaling factor 2×10^{11} or is inverse. In the TGD framework, I christened this mechanism as "scaling law of homeopathy" (sounds suicidal in the ears of a mainstream colleague) [K4]. For a UV radiation with $\lambda = 300$ nm frequency $f = 1.24 \times 10^{15}$ Hz this would mean scaling down of frequency to 6.8 kHz and scaling up of wavelength to $.4 \times 10^5$.
2. The kHz scale is one of the preferred scales suggested by the work of Bandyopadhyay, suggesting also a hierarchy of the scaling factors $2 \times 11 - 3x$, $x = -1, 0, 2, ...$ Could there exist a hierarchy of biological scales differing by powers of 10^3? Could these scaling factors correspond to various values of h_{eff}/h_0?
3. In the TGD inspired quantum biology, the Earth's gravitational magnetic body plays a key role. Could one assign the length scale with $x = -1$ with the Earth's gravitational magnetic body having gravitational Planck constant [E1] equal to $\hbar_{gr} = GM_Em/\beta_0$, $\beta_0 = v_0/c \simeq 1$, where M_E is the mass of Earth? By the Equivalence Principle, the gravitational Compton length is independent of mass m of the particle and for Earth is about .5 cm, the size scale of a snowflake.
4. The scaling hierarchy in powers of 10^3 would predict besides .5 cm, the length scale 5 μm of cell nucleus, the length scale 5 nm characterizing the thickness of the lipid layer of cell membrane and of the DNA double strand, and the scale 5×10^{-12} m to be compared with the Compton length 2.4×10^{-12} m of electron. The scaling hierarchy would be naturally associated with the electron naturally. The wavelength scale corresponding to $x = -2$ is $\lambda = .4 \times 10^8$ m, which is equal to the circumference of Earth $2\pi R_E \simeq .4 \times 108$ m defining the lowest Schumann resonance frequency!
5. If $\beta_0 = v_0/c \leq 1$ is true, the scales with $x = 0, 1, ...$ cannot correspond to the values $\hbar_{gr}$ for β_0 coming as positive powers of 10^3 and its difficult to imagine hierarchy of masses as powers of 10^3.

   Could the electric Planck constants as counterparts of gravitational Planck constants [L6], defined as $\hbar_{em} = Qe^2/\beta_0$, where Q is the charge of a system analogous to the electrode of a capacitor [L11], give these scales as electric Compton length for electron? This would conform with the fact that cell interior and DNA are negatively charged.

There are good reasons to believe that these findings will be noticed by the people fighting with the problems related to quantum computers caused by the extreme fragility of quantum coherence in standard quantum theory. One might even hope that the basic assumptions of quantum theory could be questioned. The TGD based generalization of quantum theory could pave the way for building quantum computers and also raises the question whether ordinary computers could become in some sense living systems under suitable conditions [L8, L9, L7] (see this) about the recently observed evidence for quantum coherence in mesoscales by Babcock et al [I2].

5 Conclusion

The important conclusion suggested by the experiments of Bandyopadhyay is that microtubules - in particular, brain microtubules - are at least mesoscopic quantum systems. To my personal opinion, the interpretation in the talk of Bandyopadhyay is not convincing at the level of details, and the TGD inspired modification of the proposal in terms of flux tube coordinate grids making possible TQC architectures with tubulin dimers defining bits defining in turn TQC program looks more plausible to me. A natural generalization of 1-braid TQC to 2-braid TQC is also highly suggestive in the TGD framework and could be seen as an evolutionary step assignable to the emergence of microtubules. The interpretation based on Fibonacci conduction paths fails to correctly predict

the number of resonances. An attractive interpretation for the resonance frequencies is in terms of phase transitions between A and B type lattices. If A type lattices can be generated only in h_{eff} increasing phase transitions induced by AC stimulus at resonance frequencies, one could understand their experimental absence and why a super-conductivity-like state is generated.

A lot of progress has taken place after I wrote the comments about the work of Bandyopadhyay. The findings of Babcock et al support the view that much more general systems can have this property. On the theoretical side, the understanding of the role of the long range quantum coherence assignable to long range classical gravitational fields and electromagnetic fields in the TGD framework leads to further insights about quantum aspects of not only microtubules but also other biomolecules. In particular, the universal realization of the genetic code in terms of the completely exceptional tessellation of the hyperbolic 3-space H^3 (hyperboloid of future light-cone) suggest that the genetic code is realized in several scales and that the also the linearizations as 2- and even 3-D structures are possible and that genetic code is used also for communications between biological body and magnetic body using dark photons.

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