Quantum gravitation and quantum biology in TGD Universe

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Abstract

The finding of Manu Prakash et al that animals without a nervous system behave as if they had it, is a challenge for standard biology. Similar challenges are posed by the observation that organisms without a nervous system, even plants and bacteria, have senses and purposeful motor actions, and are also able to learn. This finding led to a considerably progress in the understanding of TGD inspired quantum biology.

The TGD based view about cell and neuronal membrane, nerve pulse and EEG assumes pre-neural level which is quantal. In this view, cell membranes act as Josephson junctions and communicate sensory input to the magnetic body (MB) of the system as dark Josephson radiation. MB in turn controls the cell by dark cyclotron radiation produced as pulses as MB receives frequency modulated Josephson radiation resonantly.

Gravitational MB of Earth, which consists of very long loop-like flux tubes with gravitational Planck constant introduced by Nottale explains the findings of Blackman and others, is of special interest and assumed to play a key role in metabolism. Gravitationally dark protons would be associated with very long gravitationally dark hydrogen bonds (HBs) so that hydrogen is effectively negatively ionized. Gravitationally dark electrons or their Cooper pairs would in turn accompany gravitationally dark valence bonds connecting metal atoms or their Cooper pairs with molecules of opposite valence (hydrogen peroxide H_2O_2). Also the metal atom is effectively ionized. This provides a more accurate view of dark metal ions assumed to play a central role in the TGD inspired quantum biology.

A correct order of magnitude estimate for the upper bound metabolic energy quantum as the energy liberated as a dark proton hydrogen bond becomes ordinary is obtained. A more precise model predicts correctly the nominal value of metabolic energy quantum for proton triplets which appear also in the generation of ATP. For triplets of electron Cooper pairs, the same mechanism predicts an upper bound of the electronic metabolic energy quantum, which corresponds to the so-called miniature potential. This raises the question whether the letters of genetic code could be realized by the 4 states of electron Cooper pairs and whether the Posner molecule could realize it.

Also the gravitational MB of Sun could be involved and the prediction is that the energy range for the metabolic energy quanta corresponds to the range of visible energies so that photosynthesis could use photon energy to kick dark protons and dark electrons to the gravitational MBs of Earth and Sun to serve as metabolic energy storage.

Electronic metabolism would solve the problem due the lack of ATP machinery inside cilium and near it. This picture leads to a rather detailed model of the role of phosphate in metabolism and also to a detailed model for the pairing of DNA and dark DNA (DDNA) and forces to modify the earlier model somewhat. The quantum gravitational view about metabolism leads also to modifications of the views about nerve pulses: in particular, of the role of biologically important metal ions identified as dark ions.

Cilium can be interpreted as a predecessor of the axonal membrane and the pre-nerve pulses are predicted to be equal to miniature potentials and the reported 'spikes' as analogs of nerve pulses are assigned with de-adhesion of cilium from its neighbor or the surfaces at which the animal moves. The 'spikes' correspond to at least 100 miniature potentials just as real spikes do.

Cilium is modeled as a 2-D quantum gravitational pendulum with gravitational Planck constant controlled by MB using electronic metabolic energy quanta and the resulting model for the motion is in many respects similar to the model of nerve pulse.

Miniature spikes could appear also in plants. For the recently observed spike sequences in fungi, the voltage spike has an amplitude whose order of magnitude is consistent with the electronic metabolic energy quantum.

1 Introduction

This article summarizes the recent understanding about the biological role of quantum gravitation in the TGD Universe.

1.1 The role of quantum gravitation in TGD inspired quantum biology

In this article several new ideas related to quantum gravitation in the sense of TGD are introduced. The notion of quantum gravitational magnetic body (MB) leads to a considerably sharpening of the

existing picture and provides an improved understanding of the real nature and role of biologically important dark ions.

1. The notion of magnetic body (MB) carrying ordinary matter as phases with effective Planck constant $h_{eff} = nh_0$ suggests that MB acts as a master and ordinary matter is at the bottom of the slaving hierarchy. There are reasons to believe that gravitational flux tubes with very large value $h_{eff} = h_{gr}GMm/v_0$ of gravitational Planck constant [E1] [K14, K17] [L21, L16] are of special importance and correspond to the very high level in the hierarchy and to scales of order Earth scale. One could say that quantum gravity would transform chemistry to biochemistry and distinguish between the chemistries in *vivo* and in *vitro*.

2. Gravitational MB, which consists of very long loop-like flux tubes with gravitational Planck constant introduced by Nottale [E1] explains the findings of Blackman and others [J1], is of special interest and assumed to play a key role in metabolism. Gravitationally dark protons would be associated with very long gravitationally dark hydrogen bonds (HBs). Due to delocalization of the proton, hydrogen would be effectively negatively ionized.

   Gravitationally dark electrons or their Cooper pairs would in turn accompany gravitationally dark valence bonds (VBs) connecting metal atoms or their Cooper pairs with molecules of opposite valence (hydrogen peroxide H_2O_2). Also the metal atom is effectively ionized. This provides a more accurate view of dark metal ions assumed to play a central role in the TGD inspired quantum biology.

   A correct order of magnitude estimate for the upper bound metabolic energy quantum as the energy liberated as a dark proton HB becomes ordinary is obtained. A more precise model predicts correctly the nominal value of metabolic energy quantum for proton triplets which appear also in the generation of ATP. For triplets of electron Cooper pairs, the same mechanism predicts an upper bound of the electronic metabolic energy quantum, which corresponds to the so-called miniature potential. This raises the question whether the letters of genetic code could be realized by the 4 states of electron Cooper pairs and whether the Posner molecule could realize it.

3. One obtains a correct order of magnitude estimate for the upper bound metabolic energy quantum as the energy liberated as a dark proton HB becomes ordinary. A more precise model predicts correctly the nominal value of metabolic energy quantum for proton triplets which appear also in the generation of ATP. For triplets of electron Cooper pairs, the same mechanism predicts an upper bound of the electronic metabolic energy quantum, which corresponds to the so-called miniature potential of about .4 meV. This raises the question whether the letters of genetic code could be realized by the 4 states of electron Cooper pairs and whether the Posner molecule could realize it.

4. Also the gravitational MB of Sun could be involved and the prediction is that the energy range for the metabolic energy quanta corresponds to the range of visible energies so that photosynthesis could use photon energy to kick dark protons and dark electrons to the gravitational MBs of Earth and Sun to serve as a metabolic energy storage. Remarkably, the photosphere has temperature in thermal energy in the range [.4,.6] eV which corresponds to metabolic energy quantum.

5. This picture about dark HB leads to a rather detailed model of the role of phosphate in metabolism. Electronic metabolism could solve the problem due the lack of ATP machinery inside cilium and near it. Spikes having the same scale as miniature potentials observed in neurons could also appear in plants. For the recently observed spike sequences in fungi, the voltage spike has an amplitude with order of magnitude roughly consistent with the electronic metabolic energy quantum [I2].

6. A detailed model for the pairing of DNA and dark DNA (DDNA) emerges and forces to modify the earlier model somewhat. The HBs associated with base pairs could transform to gravitational HBs either by reconnecting directly with gravitational flux tubes or by double reconnection with gravitational HBs assignable to phosphate of the DNA nucleotide. This

process could make possible the splitting of these HBs occurring in the replication and transcription. The very weak dependence of DNA properties on various salt concentrations in vivo is in sharp contrast to the strong dependence in vitro. This difference can be understood.

1.2 TGD based view of nerve pulse

The proposed model starts from the existing TGD based view about nerve pulse but the new quantum gravitational view about metabolism leads to a sharpening of the understanding of the role of biologically important ions in nerve pulse conduction.

1. TGD leads to a quantum view [K6, K1, K7] [L14, L16] about cell membrane as a generalized Josephson junction consisting of Josephson junctions defined by membrane proteins and to the proposal that soliton sequences analogous to a sequence of rotating penduli with phase difference increasing along the axon, define the resting states of the membrane.

   Nerve pulse would be induced by a perturbation transforming rotation to vibration locally, this propagating perturbation could be called pre-nerve pulse. Also the variant, in which rotation is replaced by oscillation - one would have an "oscillon" sequence - so that perturbation would generate a propagating soliton, can be considered. Note however that one cannot associate a definite rotation direction to an oscillon. The criticality against the generation of nerve pulse has remained poorly understood.

2. TGD also leads to a speculative view about the function of nerve pulse patterns. Usually they are considered to serve as signals inside the brain. An alternative view [L14] is that they make signalling by dark photons propagating along flux tubes parallel to axons or massless extremals parallel to flux flux tubes. The synaptic vesicles containing neurotransmitters would temporarily fuse the pre- and postsynaptic neurons and also connect flux tubes to a single flux tube acting as a wave guide so that dark photon messages could propagate.

   This would make possible very rapid communications between the brain (or even MB) and sensory organs and the building of standardized sensory inputs and standardized mental images by using a virtual sensory input from the brain or MB. Essentially pattern completion and recognition would be in question. Sensory perception would be an artwork rather than photograph. Nerve pulses could also send sensory information from the neuronal membrane to MB.

3. Could the meridian system serve as a precedessor of the nervous system such that gap junctions could define permanent flux tube connections between cells? In the nervous system the connections would be dynamical and used only when needed.

The quantum gravitational view about metabolism leads to a modification of the views of nerve pulse conduction.

1. In the earlier quantum model, the cell membrane acts as a generalized Josephson junction for biologically important dark metal ions. The ground state of the axon corresponds to a soliton sequence, which has a sequence of rotating gravitational pendulums as a mechanical analog. Action potential corresponds to a soliton (or several solitons) with opposite direction of rotation.

2. In the updated model, the dark ions are identified as gravitationally dark effective ions with gravitationally delocalized Cooper pairs of dark electrons. Also gravitationally dark protons assignable to HBs are involved. The delocalization of protons and possibly also electrons to gravitational bonds provides a concrete realization for the variation of the membrane potential in the myelinated portions of the axons, where ion currents are not possible.

3. One unsolved problem of the Hodgkin-Huxley model is the conduction of neural signals through the myelinated portions of the axons, where nerve pulse is impossible. The formation of dark hydrogen- and valence bonds induces an effective ionization, which takes membrane potential below the critical value for the generation of nerve pulse, which is generated in unmyelinated portions.

4. Microtubules (MTs) are believed to be important in many quantum biological approaches and deserve a separate discussion. In the TGD framework, the quantum antenna hypothesis was one of the first proposals in this direction [K4]. Their precise role has however remained unclear hitherto.

   MTs appear in several variants. Cilia and flagella, which are analogous to axons, contain stationary MTs whereas axonal MTs are highly dynamical. The critical dynamics of axonal MTs involves a variation of MT length relying on GDP$\rightarrow$ GTP transition, which involves the change of HB to gravitational HB and vice versa changing the local membrane potential. Therefore MT dynamics makes possible the propagation of the perturbation of the membrane potential in unmyelinated portions of the axon. The effect of anesthetics can be understood in terms of a reduced density of HBs preventing the formation of gravitational HBs so that MTs and the axonal potential freeze.

The findings about multicellular animals of Prakash et al [I14, I12, I13], which have no nervous system but behave as if they had brain, provide valuable hints in attempts to understand the role of MTs. A model of the pre-neural system, based on the gravitational MB and the predicted electronic metabolic energy quantum, is developed in order to explain how these animals control their cilia. Cilia have no mitochondria inside them or in their vicinity and the electronic metabolism could replace the usual metabolism.

2 Update of the general ideas of TGD inspired quantum biology

In the sequel I develop a TGD based interpretation of findings in the conceptualization provided by TGD. I will proceed from general to specific and use cilia as example to illustrate the general ideas.

2.1 Basic motion patterns as analogs of Bohr orbits

Prakash *et al* identify a small number of basic motion patterns of cilium [I14, I12, I13]. More complex motion patterns of cell can be constructed as combinations of from these using simple rules.

For a general mechanical determiministic system 3-D initial values for generalized positions and velocities determine the time evolution and huge number of different time evolutions are possible. A chaotic behavior is much more plausible than the highly organized behavior analogous to that for organisms possessing central nervous system.

These findings resonate with the general TGD based classical description of classical physics in terms of the topology of space-time surfaces $X^4 \subset M^4 \times CP_2$ as preferred extermals (PEs) of the basic action principle [L19].

1. In the TGD framework, space-time as a 4-surface in $H = M^4 \times CP_2$ is topologically non-trivial in all scales and various shapes of matter, usually assigned to matter in almost flat and topologically trivial space-time of general relativity, correspond directly to the topology of the space-time surface.

2. From the general coordinate invariance, space-time surface is a preferred extremal (PE) of a general coordinate invariance action principle, which realizes holography in the sense that 3-surface as boundary values determines almost completely the 4-surface, which is therefore analogous to Bohr orbit. There is however a small failure of determinism localizable at the singularities where minimal surface property fails. PEs are minimal surfaces with singularities analogous to frames of ordinary soap films [L23].

3. The space-time counterparts of all biological and neurological functions (this includes the development of mechanical and electromagnetic patterns such as nerve pulse patters) correspond to PEs. PEs are also analogous to the modules of computer programs. A small failure

of quantum determinism corresponds to a selection of sub-modules in branching points and correspond to the non-determinism of soap films with frames.

4. Zero energy ontology of TGD which predicts that quantum states of a system are superpositions of space-time surfaces as preferred extremals (PEs) of action. "Small" state function reductions (SSFRs) as the TGD counterparts of "weak" measurements would select between different variants of space-time surface with same singularities (frames of soap film) and BSFRs would correspond to big changes.

   The small repertoire of different motion patterns would correspond to a collection of PEs. From these patterns for cilia more complex patterns would be constructed for the motion patterns for a cell would emerge. From the patterns for cell motion the patterns for a multi-cellular system would emerge. There would be a hierarchy of complexity reducing to a hierarchy of extensions of rationals at fundamental level.

2.2 Quantum criticality

Also cilium and a ciliary system could be near quantum criticality and this could be essential for the changes of the state of the motion of cilia.

The motions of microtubules inside cilia force the bending of cilia. The beating waves with frequency 4-10 Hz propagating along cilia and having constant phase along a 1-D section curve of the 2-D transverse section of transversal plane of cilium are known to induce the motions of a single cilium. In multicilium system these motions are in the same phase and induce coherent motion

When the height h, the orientation of cilium, and the beating frequency f are near criticality, a BSFR would occur and induce a sudden change in the motion of cilium. The criticality of the beating frequency could mean resonance between the microtubuli inside cilium and BSFR would induce the shortening of the flux tube pair connecting them. This would induce the bending of the flux tube.

The presence of 3 parameters suggests a catastrophe theoretic description using Thom's catastrophe theory based on a butterfly catastrophe with 3 control parameters.

2.3 Excitable systems in zero energy ontology

In the TGD framework, the idea that excitable systems as systems making "big" state function reductions (BSFRs) as counterparts of ordinary SFRs in macroscopic spatial and temporal scales is suggestive. In BSFR the arrow of time changes and after BSFR the dissipative development occurs in reverse time direction and looks to the observer with the standard arrow of time like self-organization and generation of patterns. This BSFR is followed by second BSFR re-establishing the original arrow of time.

In quantum critical systems, the value of h_{eff} would be fluctuating and the change of h_{eff} could happen in BSFR. The dynamics of microtubules (MTs) could be quantum critical since it involves continual growth and decay of MTs, which would correspond to a sequence of BSFRS. During mitosis (cell replication) the expansion and contraction of MTs involving change of h_{eff} and BSFR would play a key role role.

Bio-catalysis is another example [L28]. The reactants would be brought near each other by a contraction of the flux tube pairs connecting them. The flux tubes pairs would be formed by a reconnection of U-shaped flux tubes of reactants acting as tentacles if there is cyclotron frequency resonance (the thicknesses of the U-shape flux tubes are identicals). The BSFR involving a contraction due to the reduction of h_{eff}. After reaction h_{eff} could reduce to its original value in second BSFR.

2.4 The notions of magnetic and electric body

The notions of magnetic body and electric body are central in TGD inspired quantum biology but their precise definition has been far from clear. The intuitive notion is that MB consists of U-shaped monopole flux tubes extending from the system considered and serving as kinds of tentacles. These

flux tubes for two systems can reconnectand form a pair of flux tubes connecting the system if the cyclotron frequencies of the tubes are the same so that cyclotron resonance becomes possible.

MB is characterized by the value of the effective Planck constant $h_{eff} = nh_0$, where n corresponds to the dimension of the extension of rationals assignable to the space-time regions by $M^8 - H$ duality [L11, L12]. One can assign MB to flux tubes mediating electromagnetic, gravitational and even weak and color interactions, and the scale of MB correlates with the screening length of these interactions. For gravitation there is no screening and the values of $h_{eff} = h_{gr}$ can be very large. The large value of $h_{gr} = GMm/v_0$ [E1] implies that the dark cyclotron radiation in the EEG range would correspond to visible and UV energies.

In the TGD framework magnetic body (MB) would serve as the controlling agent receiving sensory information as a frequency modulated dark Josephson radiation and controlling the cell by using dark cyclotron radiation coming as pulses corresponding to resonant receival of Josephson radiation.

What could be the electric counterpart of the magnetic body? Magnetic flux tubes can also be dynamical and locally orthogonal helical magnetic and electric fields are possible. Electric body should be something different. Various membrane-like structures populate the Universe and they could correspond to electric bodies.

1. The 4-surfaces X^4 with 1-D CP_2 projection and 3-D M^4 projection having 2-D membrane as E^3 projection are good candidates for various membrane objects in TGD Universe [L23]. The E^3 projection is not a minimal surface although X^4 is, and this possible if the 1-D CP_2 projection is dynamical. The flux tubes of MB should be assignable to kind of membrane-like surface.

2. The gravitational MB, it it exist, could be a layered structure containing the Bohr orbits with Bohr radii $r_n \propto n^2$ of particles in the gravitational field of Earth. Particles with different masses would concentrate at the same orbits. One would have the shell structure of the ordinary atom. This notion generalizes also to other interactions and for them the values of h_{eff} would be much smaller.

3. Flux sheets with a cylindrical rotational symmetry containing the orbits can be considered. These surfaces should be realized as preferred extremals of the action and should be minimal surfaces in $H = M^4 \times CP_2$. As closed surfaces they cannot define minimal surfaces of the Euclidean 3-space E^3. Indeed, soap bubbles are not minimal surfaces but require a constant pressure difference between interior and exterior.

   The analog of the pressure difference would be non-trivial and dynamic 1-D projection of 4-D surface to CP_2 [L23]. The liberation of metabolic energy quantum would be analogous to a transition of hydrogen atom to a lower energy state.

2.5 The notion of gravitational magnetic body

The notion of gravitational MB turns out to be crucial for the understanding of the role of quantum gravitation in TGD inspired quantum biology.

2.5.1 Gravitational magnetic body as a controlling agent and the prediction of two metabolic energy quanta

In the TGD framework magnetic body (MB) would serve as the controlling agent receiving sensory information as a frequency modulated dark Josephson radiation and controlling the cell by using dark cyclotron radiation coming as pulses corresponding to resonant receival of Josephson radiation.

The large value of $h_{eff} = h_{gr} = GMm/v_0$ [E1] implies that the dark cyclotron radiation in the EEG range would correspond to visible and UV energies.

The intuitive notion is that MB consists of U-shaped monopole flux tubes extending from the system considered and serving as kinds of tentacles. These flux tubes for two systems can reconnect and form a pair of flux tubes connecting the system if the cyclotron frequencies of the tubes are the same so that cyclotron resonance becomes possible.

In [L24], the question of what the notion of gravitational MB does mean, was considered.

1. The dark flux tube would be "gravitational" with $h_{eff} = h_{gr}$. Gravitational flux tubes carry Kähler monopole flux but no gravitational flux. This would be in conflict with the irrotational nature of gravitational field at Newtonian limit. The monopole flux could however have interpretation as gravimagnetic flux. The attribute "gravitational" is motivated by the assumption that one has $h_{eff} = h_{gr}$. The ordinary, shor, HB reconnects atoms A and B.

   Gravitational flux tubes have lengths, which can be of the order of Earth size scale and the radii of gravitational Bohr orbits define a natural scale form them. Gravitational flux tubes are closed flux tubes with the shape of a highly flattened triangle with a long side in the vertical direction and having length of order Earth size scale and short side of order interatomic distance for the atoms A and B connected by HB.

   This inspires a rather concrete vision about the structure of gravitational MB as a forest of gravitational flux tubes analogous to trees. This applies also to non- gravitational flux tubes with smaller values of h_{eff}. One would have a full magnetic flora. The larger the value of h_{eff}, the more complex the magnetic plant would be. MB would be like a fractally scaled-up variant of the ordinary forest. Reconnections would make possible transfer of gravitational flux tubes so that also magnetic fauna would be present.

2. One obtains gravitationally dark hydrogen bond (HB) from an ordinary HB when a HB from A to B reconnects with a pre-existing long gravitational flux tube to create a very long gravitational flux tube from A to B. Proton is delocalized as a gravitationally dark proton and its gravitational potential energy is reduced so that the flux tube stores metabolic energy. In the reverse process a reverse reconnection takes place and this metabolic energy is liberated.

   The reconnection process requires a feed of energy: for instance solar radiation can provide it in photosynthesis. A similar description applies in the case of valence bonds (VBs). Note that the transformation of an ordinary, short HB to a long gravitational HB is not a realistic option since this would require a lot of energy since magnetic energy would be created.

3. The elongated gravitational flux tubes could correspond to either hydrogen bonds (HBs) or valence bonds (VBs). The loop-like bond could connect nearby atoms just like the ordinary bond. The delocalization of the charge to the flux tube leads to an effectively ionized donor atom.

4. All values of h_{eff} are possible. For electromagnetic flux tubes the values of h_{eff}/h are not very large. This picture leads to a view about hydrogen and VBs as bonds having $h_{eff}/h > 1$ [L5]. Also gravitational variants of hydrogen and VBs are possible. In this case, the proton or electron would be vertically delocalized in the Earth scale so that the donor atom would be effectively ionized. For instance, a phosphate ion could be an effective ion having a gravitational hydrogen bond with the hydrogen of a water molecule.

5. A gravitational VB, connecting a metal atom with an atom with an opposite valence, would lead to effective ionization of the metal atom. For instance, biologically important bosonic ions such as Ca^{++}, Mg^{++}, Fe^{++} and Zn^{++} associated with their oxides could correspond to effective ions like this.

   The signature would be a pairing with a neutral oxygen atom by a gravitational VB. I have introduced the notion of dark ion to explain the findings of Blackman [J1] and others and dark ion could correspond to this kind of pair. Note that the original variant of the model assumed that the entire ion is dark, the later version assumed that the valence electron of free atom is dark, and the model considered here assumes that darkness is a property of bond.

6. The effective ionization requires energy ΔE to compensate the increment of the gravitational potential energy given by $\Delta E_{gr} = (\langle V_{gr}(R)\rangle - V_{gr}(R_E))$. Here $E_{gr}(R)$ is gravitational potential energy proton or electron, and R_E denotes the radius of Earth, and R is the distance of the point of flux tube from the center of Earth.

   Classical energy conservation suggests that the value of vertical kinetic energy at the surface of Earth is equal to the increment of the gravitational potential energy at the top of the loop. From energy conservation one can estimate the metabolic energy quantum as a liberated

kinetic energy in the normal direction equal to the increase of gravitational potential energy. Hence the naive guess could be correct.

7. The maximal value for ΔE_{max} for electron Cooper pair (dark Cooper pair is at infinite distance) corresponds to $V_{gr}(R_E) = .36$ meV to be compared with the energy scale .3 meV defined by the temperature of 3 K microwave background and to the value .4 meV of the miniature potential. This suggests that, in the case of the electron, the reduction of kinetic energy contributes more than 10 per cent to the ΔE.

   For a single dark proton one has $V_{gr}(R_E) \simeq .34$ eV, which is below the nominal value of the metabolic energy currency about .5 eV.

8. The condition that the end of the vertical gravitational loop travels along a stationary orbit parallel to the plane of rotation of Earth such that the normal velocity of the dark particle vanishes at the top, implies for the tangential velocity v_T the condition $v_T^2 = \omega^2 R^2 = GM/R$ allowing to determine the radius of the orbit as

$$\frac{R}{R_E} = (\frac{r_{s,E}c^2}{2\omega^2})^{1/3} \times \frac{1}{R_E} \simeq 3.1 \quad .$$

   The change of the gravitational potential energy in the transition to an ordinary proton would be $\Delta E = \Delta E_{gr} = .68 \times V_{gr}(R_E)$, which would give $\Delta E = .18$ eV. In the dark genetic codons hydrogen bonds appear as triplets. 3 dark protons would give metabolic energy quantum .55 eV. Interestingly, a translocation of 3 protons fuels synthesis of ATP!

9. For an electron Cooper pair the upper bound for the metabolic energy quantum would be $\Delta E_{max} = .33$ meV, which is below the miniature potential .4 meV. For the stationary flux tubes one obtains $\Delta E = .17$ meV. Later the evidence for the 'spikes' in fungi [I2] discovered by Adamatsky will be discussed: their amplitude is reported to be in the range .03-2.1 meV which contains ΔE.

   For an electron Cooper pair triplet one would have $\Delta E = .51$ meV consistent with the miniature potential .4 meV. Should one take this seriously? Could also dark electron Cooper pairs organize into triplets like dark protons would do and in this manner define dark genetic code? TGD predicts that genetic code is universal: could also dark electron Cooper pairs define a dark variant of the genetic code?

   Posner molecules $[(PO_4)^{-3})]_6Ca_9^{+2}$, to be discussed in the sequel, consists of 3 $[(PO_4)^{-3})]_2Ca_3^{+2}$ acting as a basic unit. This unit could contain 3 electronic Cooper pairs with electronic metabolic energy quantum $\Delta E = .51$ meV. In principle, Cooper pairs can have spin 1 or spin state giving 4 states altogether. Could these states define letters of a dark genetic codon so that the basic unit would define a genetic codon and Posner molecule could correspond to a triplet of genetic codons?

   The TGD view about formation of bound states as Galois singlets [L27] allows us to consider this possibility. For an extension of extensions of ... the Galois group would decompose to a hierarchy of Galois groups actings as normal subgroups. Codons as triplets would be Z_3 singlets in both the ordinary and the electronic genetic code. Genes would correspond to larger Galois groups decomposing to normal subgroups. Codon doublets of DNA double strands would be Z_2 singlets and triplets of triplets of Posner molecules would be Z_3 singlets.

10. A proper treatment of the situation would require Schrödinger equation for the dark particle at the flux loop. The situation is analogous to a quantum model of the fountain effect of super-fluidity discussed in [K15] in a situation when the gravitational potential can be linearized (WKB approximation).

    One can consider Schödinger equation for h_{gr} idealizing the loop with a 1-D box with gravitational potential GMm/r. The Schrödinger equation reduces in dimensionless variable $u = (m/\hbar_{gr})z = 2\beta_0(z/r_s)$, $r_s = 2GM$ to

$$(-\frac{\partial_u^2}{2} - \frac{\beta_0}{u})\Psi = \frac{E}{m}\Psi \equiv \epsilon\Psi \quad .$$

A possible condition is that the vertical derivative $\partial_z\Psi$ vanishes at the top of the loop. The metabolic energy quantum equals $(GM/R_E - \epsilon(v))m$ and is quantized. The height of the loop could be quantized using the condition that the loop end is stationary with respect to Earth.

If this speculative picture makes sense, quantum gravitation would play a key role in metabolism and genetic code.

1. The transformation of electrons and protons between ordinary and gravitationally dark states would be a key process of metabolism and biocatalysis. This conforms with the fact that proton and electron exchanges play a key role in biology. For instance, phosphorylation means that the receiving molecule gains phosphate, which can form gravitationally a dark hydrogen bond so that the system becomes metabolically active. This would correspond to the activation in bio-catalysis.

2. In the same way, in a redox reaction, the electron donor is oxidized and the electron receiver is reduced. Reduced molecule gains the ability to have a gravitationally dark electron, and therefore becomes metabolically active in the electronic sense. Redox reaction would be the electronic counterpart for phosphorylation.

2.5.2 The role of solar gravitational field in metabolism

Also the gravitational field of the Sun could be important in metabolism.

1. At the distance of 1 AU of the Earth, the counterpart of single proton metabolic energy quantum .18 eV would be 2.6 eV, which is in the visible range. For a proton triplet, the energy would be 7.8 eV and in the UV range. This quantum would be realized as a long flux tube directed away from the Sun in the plane of the Earth's orbit and orthogonal to the orbit.

2. Could the visible solar radiation kick protons to solar gravitational flux tubes and the radiation of photosphere having energy range [.4,.6] eV to the gravitational flux tubes of Earth in photosynthesis? Could the solar part of dark gravitational energy for protons be transformed to ordinary metabolic quanta in metabolism? Note that the feed of the solar radiation energy to flux tubes suggests a modification of the proposed simple model involving only gravitation.

3. This picture would be true for all Sun-like stars and for planets at the distance of Earth and supports the view that Earth-like planets for Sun-like stars are favourable for life.

2.5.3 Metabolic energy depends on gravitational environment

According to the proposed simple model, bio-chemistry would strongly depend on the local gravitational environment.

1. For an object with mass M and radius R, the estimated maximal gravitational metabolic energy quantum E_{max} is scaled up by factor is scaled up by a factor $z = (M/M_E) \times (R_E/R)$. The values of z for Mercury, Venus, Mars, and Moon are (.2,.14,.86,.04). For Venus, which is called the sister planet of Earth, z is not too far from unity.

   For the stationary orbits around an object with radius R_1, mass M_1, and rotation frequency ω_1 the ratio $\Delta E_1/\Delta E_E$ of metabolic energy quantum to that for Earth satisfies the scaling formula

$$\begin{array}{lll} \frac{\Delta E_1}{\Delta E_E} = \frac{R_E}{R_1} \times (1 - x_1x_2x_3) & & , \\ x_1 = (\frac{M_1}{M_E})^{1/3}\ per, & x_2 = \times(\frac{\omega_E}{\omega_1})^{2/3} \ , & x_3 = \frac{R_E}{R_1} \end{array}$$

2. In the case of the Moon, E_{max} would be by a factor $z = R_E/R_{Moon} = .017$ smaller than at the surface of Earth. The stationarity condition would require a flux tube orbit radius smaller than the Moon radius. In the case of Venus, the sidereal rotation period is -243.0 days (retrograde): also now the orbit of stationary radius would be smaller than the radius of Venus. This suggests that only the metabolism utilizing the solar gravitational field photosynthesis is possible and would be essentially the same as at the surface of Earth.

3. In the case of Mars one has $\omega_1/\omega_E \simeq 1$, $M_1/M_E = .1$, $R_1/R_E = .533$. This gives $\Delta E = .24\Delta E_E$, which for the proton Cooper pair would give .13 eV. Could the solar gravitational field save the space traveller in case of Moon and Mars? The largest distance from Earth is about 1.7 AU and at this distance the maximal value of the solar metabolic energy quantum is scaled down by a factor .59.

Jupiter's (`https://cutt.ly/CF8bteR`) moon Europa (`https://cutt.ly/HF8buAp`) is one of the most promising candidates for a seat of life since it contains water in the form of ice. Is quantum gravitational metabolism based on the solar and Jovian gravitational fields consistent with Earth-like metabolism?

For the Jupiter's gravitational field, the gravitational potential energy at the surface of Europa is $V_{gr} = GM_Jm/R_{Eu}$ and defines the maximal value ΔE_{max} of the metabolic energy quantum for a flux loop defining dark gravitational HB oriented radially outwards along A line connecting Europa and Jupiter. The mean distance d_{Eu} from Jupiter is $d_{Eu} = 105.3 \times R_E$ to be compared with the radius $R_J = 10.97R_E$ of Jupiter. The mass of Jupiter is $M_J = 317.8M_E$. This gives $\Delta E_{max,Eu}/\Delta E_{max,E} = V_{gr,J}/V_{gr,E} = (M_J/M_E) \times (R_E/d_{Eu}) \simeq 3.0$.

For a single gravitationally dark proton, the maximal metabolic energy gain would be .99 eV, which is twice the metabolic energy quantum. Standard metabolic energy quantum .5 eV corresponds to a radially oriented loop with height $h = d_{Eu}$. If a proton triplet defines the metabolic energy quantum, one would have $h = (1/5)R_{Eu}$.

Solar radiation should provide metabolic energy. The average distance d_J of Jupiter from Sun varies between 5.0AU and 5.4AU so that the gravitational metabolic energy quantum has upper bound $\Delta E_{gr,Sun,J} \leq \Delta E_{gr,Sun,E}/5 \simeq .5$ eV, which corresponds to metabolic energy quantum. Photosphere produces IR radiation with energies in the range .4-.6 eV. Therefore Europa seems to satisfy the conditions from quantum gravitational metabolism.

Just for fun, one can also look at the situation at the surface of Sun.

1. At the surface of the Sun, one has $z \simeq 3.0 \times 10^2$ and the metabolic energy quantum .55 eV for dark proton triplet scales to $\Delta E_{Sun} \sim .16$ keV: this is below the threshold for the nuclear fusion and below the temperature of $\sim .23$ keV of the solar corona. An interesting question is whether the X-ray radiation arriving to Earth could have some, perhaps even biological, function. TGD indeed predicts that nuclei have excitations in the keV range [K16].

2. For a dark electron Cooper at solar surface, the upper bound is .08 eV. The temperature of the photosphere corresponds to photon energy of .4-.6 eV, which corresponds to the metabolic energy quantum associated with the Earth's gravitational flux tubes. Could the IR thermal radiation from the photosphere serve as a metabolic energy source?

How does this model relate to the TGD inspired model for Cambrian Explosion [K2] [L22] ?

1. The TGD explanation for the sudden emergence of new phyla in Cambrian Explosion is that the radius of Earth doubled in CE in rather short time. If the end of flux tube moves along stationary orbit, the scaling formula gives for the metabolic energy quantum before the transition for the dark proton triplet the value $\Delta E_{gr} = .38 \times \Delta E_{gr,max}$, which gives $\Delta E_{gr} = .3$ eV. This is considerably smaller than .55 eV.

2. According to Stephen Gould (see the book "Wonderful life" about Burgess Shale Fauna [I17]), a large number of the phyla suddenly disappeared. Could this mean that they were not able to adapt to the transition increasing the value of the metabolic energy quantum? On the other hand, a rapid evolution started. Could this relate to the increased sizes of the protonic and electronic metabolic energy quanta? Solar metabolic energy quanta would not have changed.

2.5.4 Do Moon travellers survive in TGD Universe?

3 dark protons give the nominal value of metabolic quantum. If the naive estimates are taken seriously, terrestrial life might not be possible on Mars and Moon. Humans have however successfully visited the Moon and it is not clear whether the solar gravitational field comes to rescue.

Rather than giving up the idea, it is better to ask what goes wrong with the simplest model. The quasiclassical estimate assumes that the dark charge at the top and bottom of the gravitational flux tube has the same kinetic energy. If the kinetic energy at the top is higher, the value of the metabolic energy quantum increases. This inspires the question whether the reduction of the kinetic energy in the metabolic energy quantum can be neglected.

1. The simplest model for the particle at gravitational VB is as a particle in a box with kinetic energies given by $E_n = n^2\hbar_{eff}^2/mL^2$, L the length of the loop. If L scales like h_{eff}, the kinetic energy does not depend on h_{eff}. Therefore the scale of kinetic contribution can be estimated in a molecular length scale.

2. Could the system adapt to a reduction of the maximal gravitational potential at the surface of the Moon, Mars, or Venus by increasing the average value of n in the superposition of the standing waves having maximum at the top of the valence loop? The system would adapt by increasing the localization of the dark charge at the top of the loop. The reduction of the bond length would mean reduction of the superposition to $n = 0$ wave so that the kinetic energy would be indeed liberated.

2.5.5 Dark gravitational bonds and high energy phosphate bond

How could the somewhat mysterious high energy phosphate bond (HEPB) associated with di-phospates (DP) and tri-phosphates (TP) relate to the gravitationally dark hydrogen bonds (HBs)?

1. HEPB (`https://cutt.ly/2FcLFJY`) is identified as the bond $... - -O - -...$ connecting two P atoms in ATP or ADP (`https://cutt.ly/HFcLKyk`). Hydrolysis involves also one H_2O molecule. The $-O - P$ bond splits inducing the splitting of ATP to ADP and P_1. One cannot assign HEPBs to the monophosphates (MPs) associated with DNA so that the splitting of the O-P bond must play an essential role..

2. It is best to start by listing the facts about $ATP \rightarrow ADP + P_i + 2H^+$ reaction for which the Wikipedia article (see `https://cutt.ly/xFbuDet`) gives both graphical representation and the overall formula for the reaction.

   In the initial state 4 O-atoms of ATP have a visible negative charge. The simplest assumption is that all ions O^- actually correspond to gravitationally hydrogen bonded $O...H$ pairs with a delocalized proton charge so one should use the notation $O^{"-"}$. O^- would be replaced with $O...H - O - H$ such that the HB carries a gravitationally dark proton delocalized in even astrophysical scale. The negative charge would be only effective and associated with $OH^{"-"}$ rather than being a real negative charge of O^-. The same assumption is natural also for ADP and AMP. This would define the meaning of organic phosphates. In the final state both P_i and ADP have visible charge -3 to give a total visible charge -6.

   $2H^+$ in the final state guarantees the conservation of the visible charge in the reaction.

3. The $P(O^{"-"})_2$ of the third phosphate transforms to an inorganic phosphate P_i. A natural interpretation is that the gravitationally dark protons become ordinary ones. This explains $2H^+$ in the final state. This reaction would liberate part of the metabolic energy.

4. One H_2O molecule is used in the reaction. The natural assumption is that one hydrogen of H_2O has a dark gravitational HB with the oxygen appearing in $O - P$ of $(O_2^{"-"}P = O) - O - P...$ so that it one has $O^{"-"}$ visible charge -1. The bond $...P - O - ...H$ becomes the effective oxygen ion of $...P - O^{"-"}$ of P_i so that P_i would not be completely inorganic. The remaining OH of the water molecule becomes one $O^{"-"}$ of P of ADP. Also this reaction can liberate metabolic energy.

2.6 Gravitational magnetic body and the model of dark DNA

Dark DNA (DDNA) is identified in terms of dark proton triplets assigned with flux tubes parallel to DNA. Codons correspond in the original model to smaller circular flux tubes carrying the dark proton triplets. This model is modified by replacing the circular flux tubes with long U-shaped

gravitational HBs. In order to avoid confusion, one must make clear that this realization of DDNA differs from that discussed in [L27] and one must check whether they are consistent and what new predictions follow from the recent, much more specific, model.

2.6.1 Original model of DDNA

The original proposal for DDNA was that the dark proton charge screens the negative charge of phosphates so that the charge associated with the DDNA codon would be +3. If one has dark nucleons (proton and neutron), also other charges than +3 are possible in the proposed model and would be needed for amino acid polymers (AAs) [L27].

The most recent model discussed in [L27] made the following assumptions.

1. Dark nucleotides correspond to closed loops containing a dark nucleon: both dark protons and possibly effectively dark neutrons are possible so that dark nucleon has spin and strong isopin corresponding to 4 letters of the genetic code. A dark neutron could be only effectively a neutron and could be formed from a dark proton, which has transferred its charge to a flux tube connecting it with the neighboring dark proton.

   The total charge is that for dark protons as required by the condition dark DNA charge is neutralized. This conforms with the model for the formation of dark protons by Pollack effect [I8, L3, I19, I15] as transfer of ordinary protons to dark protons at flux tubes possibly forming dark codons as dark proton triplets [L3].

   The flux tube could be regarded as analogous to dark π^0/π^- or dark Z^0/W^-. These two options could be dual descriptions as the conserved vector current and partially axial current hypothesis of old fashioned hadron physics suggest.

2. The loop carries angular momentum and the angular momenta of dark protons and dark nuclei sum up. The tensor product decomposition of the states obtained in this manner gives DDNA, DRNA, DtRNA, and DAA therefore unifying the counterparts of the basic biomolecules at the dark level.

3. A natural expectation is that $h_{eff} = nh$ forms the unit of angular momentum, in particular spin. This gives a very strong condition and strongly suggests that dark particle corresponds to n-particle as analog of Bose-Einstein condensate: dark 3N-protons and dark 3N-photons as representations of genes with N-codons have been indeed suggested to play a key role in TGD inspired quantum biology. Dark photons with energy of $E = h_{eff}f$ would correspond to $n_{eff} = h_{eff}/h$ dark photons forming an analog of BE-condensate.

   Dark space-time sheets X^4 correspond to n-sheeted structures with Galois group of n-D extension of rationals. Many-sheetedness could correspond to many-valuedness of X^4 as a map $M^4 \to CP_2$ or vice versa and one can have also have n_1- and n_2 valuedness with $n = n_1 n_2$. In fact, one has a natural factorization of the order of the Galois group to a product of integers corresponding to its decomposition to normal subgroups so that $n = n_1 n_2 ... n_k$ is the general proposal. n_{gr} (assigned to h_{gr}), n_{em} , n_{weak}, n_{color} can have further decompositions. n-sheetedness with respect to CP_2 would correspond to n copies of a space-time sheet in M^4, for instance parallel flux tubes forming a quantum coherent structure. For $\hbar_{gr}$ this would be the natural option and for $n_{gr} = \hbar_{gr}/\hbar = n_{gr} \sim 10^{14}$. In this case, N-codon interpretation is not appropriate not natural, rather n_{gr} gravitationally dark DNA flux tubes could integrate to a quantum coherent parallel structure with a size about 1 mm.

2.6.2 The revised model of DDNA

In the model of DDNA-DNA considered here gravitationally dark HBs would define the dark codons.

1. The earlier model is modified by replacing the closed flux tubes associated with the dark nucleons with gravitationally dark HBs.

2. There is no screening now, and the negative charge of phosphates is only effective and assignable to water molecules surrounding DNA rather than phosphates directly so that DNA stability would be achieved also now.

3. Dark DNA has still effective charge -1 per codon and the dark proton charge would be delocalized at the dark gravitational flux tubes and thus invisible. DDNAs would be connected by quantum numbers of loopy flux tube pairs with quantum numbers π^0 or π^- connecting dark nucleons of dark DNA. A dark proton at the strong flux tubes would transform to an effective dark neutron in the case of π^-. The value of h_{eff} for these would most naturally correspond to h_{color}.

   I have proposed that even the nucleons of ordinary nuclei can have dark flux tubes, which emanate from nuclei of nuclei and carry quantum numbers of pions and having size of even atomic scale. This could relate to the observed discrepancy of the radius of protons. As a matter of fact, this would mean the counterpart of dark HBs at the level of strong interactions.

4. What is new as compared to the earlier model is that there would be a composite of n_{gr} more or less parallel DNA flux tubes assignable to a volume of order 1 mm and each having a length proportional to $\hbar_{gr}$. Also single flux tube visiting through all the DNAs can be considered. One would have a flux tube spaghetti also assumed to be generated in the formation of astrophysical objects [L7, L9, L20].

2.6.3 Could the HBs associated with the base pairs of DNA become gravitationally dark?

DNA base pairs are connected by 2 (A-T) or 3 (G-C) HBs: what could this mean from the point of view of DNA energy metabolism?

1. If these strands can appear as dark gravitational strands, the maximum of 2 (3) metabolic quanta could be liberated in A-T (G-C) pairs via a transformation to ordinary HBs. Could this serve as a yet-unidentified source of metabolic energy in the replication and transcription?

2. Could the dark/organic mono-phosphates of the double DNA strand serve as a source of metabolic energy for DNA transferred to the HBs connecting base pairs?

3. Suppose that the DDNA parallel to DNA corresponds to a sequence of gravitational HBs B_{gr} as loops associated with the organic phosphates. Codon would correspond to a bound state of dark protons associated with three dark gravitational HBs.

   Consider an ordinary HB A_{ord} associated with a base pair and B_{gr} associated with the corresponding dark/organic phosphate. Can one transform A_{ord} to A_{gr} to achieve the transfer of metabolic energy?

   Two reconnections for a HB pair (A_{ord}, B_{gr}) can transform the pair to (A_{gr}, B_{ord}). The gravitationally dark proton and metabolic energy would be transferred to basepair from the organic phosphate, which itself would become an organic phosphate ion P_1^-.

   Note: Also the phospholipids of the cell membrane are accompanied by a monophosphate group. Also microtubules are accompanied by GMPs. Could they serve as metabolic energy sources in the cell membrane using the above described mechanism?

2.6.4 A quantum gravitational mechanism for the splitting of HBs associated with base pairs

The splitting of HBs associated with base pairs [?]`https://cutt.ly/9FmJywe`) plays a fundamental role in DNA opening necessary for DNA replication and transcription. These HBs must split during replication and transcription and many other processes such as selective recognition of DNA by proteins, regulation of RNA cleavage by site-specific mutations, and intermolecular interaction of proteins with their target DNA or RNA. Could the notion of gravitational HB provide insights about the process?

1. As the figures of (https://cutt.ly/PFmJaFr) illustrate, the base pairs of the double DNA/RNA strand have 2 or 3 HBs. HBs of type $N-H...O$ and $H-N...O$ and $N-H...N$ (called imino HB) are possible. Imino HB appears for both A-T with 2 HBs and G-C with 3 HBs.

   Since the hydrogen of $X-H...Y$ is nearer to Y than X, the splitting is expected to give $X+H-Y$, $X,Y\in\{N,O\}$. This is indeed the case when X and Y are different. However, the imino HB $N-H...N$ actually splits to $N-H+N$ rather than the expected $N+H-N$. An exchange of a hydrogen atom is said to occur.

2. The temporary formation of a gravitationally dark HB could explain how this is possible. The gravitationally dark proton is at a large distance from the N atoms so that they are in a symmetric position and both outcomes for the splitting are equally probable so that the exchange rate increases.

3. This requires a temporary transformation of $N-H...N$ HB to a gravitationally dark HB. Could double reconnection transform the pair $(A_{ord},B_{gr}$ formed by $N-H...N$ HB and dark HB of phosphate bond to (A_{gr},B_{ord}), which then splits?

2.6.5 Quantum gravitational explanation for the different chemistries in vivo and in vitro

If gravitationally dark hydrogen and VBs are relevant to biology, their effects should distinguish between matter in vivo, gel phase and matter in vitro. The difference should be especially clear at physiological temperatures. Is there any empirical evidence for the deviations from what is inspected on the basis of the standard biochemical intuition?

The interactions between DNA metal ions present living matter could serve as a test for the proposal. In the TGD framework, both metal ions and DNA could be gravitationally dark (in vivo or gel phase) or ordinary (in vitro phase).

1. For the DNA and metal ions as they are usually understood, the phosphate ions $(PO_4)^-$ of DNA should have interactions with metal ions and the concentrations should affect the properties of DNA. This should be true both in vivo and in vitro.

2. In the TGD framework, DNA strand in vivo and in gel phase would be accompanied by a dark DNA strand. The phosphate ions $(PO_4)^-$ would be actually pseudo-ion $(PO_4)^{"-"}$, in the sense that the ion O^- would be replaced with a gravitationally hydrogen bonded structure $O...H-O-H$ such that the HB carries a gravitationally dark proton delocalized in a very long scale. The effective negative charge would be associated with $OH^{"-"}$ pseudo ion rather than being a real negative charge assignable to O.

   Outside the physiological temperature range and in vitro, the oxygen ion would be real and the situation would be as in the standard chemistry apart from the possible effects of darkness of metal ions. The simplest assumption is that both metal ions and DNA are dark at the same temperature range only.

3. (Gravitationally) dark metal ions of type X^{++} would also have a dark valence electron at flux tube. One can speak of dark salt since flux tube bonds would connect X with H_2O_2. Same applies to Cooper pairs of dark ions X^+.

   The phosphate of DDNA-DNA pair has Coulomb interaction with neither ordinary nor dark ions but the metal ion would interact with $OH^{"-"}$. This suggests that the presence of metal ions does, and ions in general, has no strong effect on the DNA properties in vivo. Besides realizing genetic code, dark DNA would shield the system from the perturbations caused by various ions.

4. Experimentally this seems to be the case. Most interactions between DNA and ions are modelled and studied experimentally in dilute water solutions. According to [I6] (https://cutt.ly/bFQ1Gla), under these conditions the DNA interaction with charged ligands, the helix-coil transition temperature, and other DNA properties are strongly dependent on the low-molecular-weight salt concentration, see [I6] and references therein. However, for

condensed DNA states (fibers, gels) or in vivo, similar characteristics are often independent of or only slightly dependent on the ionic composition of the solvent.

What about amino-acids (AAs)? The proposal is that also DAA-AA pairing realizes dark genetic code. If this code is realized in terms of gravitationally dark HBs, one expects that the same should be true for AAs.

2.6.6 Dark proteins and quantum gravitation

What about dark proteins in the recent situation?

1. In the case of AA of a protein, the effective charge is assignable to the donor atom, which could be either atom of peptide backbone or of water molecule. Can one assign to a given amino acid (AA) of protein (`https://cutt.ly/sFRYlWA`) 3 gravitational HBs carrying a dark proton each?

2. In the formation of AA sequence, peptide bonding occurs, which means that $(C = 0) - (OH)$ is replaced with C=O and NH_2 is replaced with $N - H$. $(N - H) - (C - H) - (C = O)$ is the unit of peptide backbone (`https://cutt.ly/nFRYnu4`).

   The H atom of $N - H$ could form a gravitationally dark HB to O atom of water molecule, which would give $N^{"-"}$. Also N could form HB with H of water molecule: this would give $OH^{"-"}$. $C = O$ could form a dark HB with the H of the water molecule so that $OH^{"-"}$ is generated but $= O$ remains neutral. As in the case of DDNA-DNA pair, an effective negative charge of -3 units would be generated if one counts also the $COH^{"-"}$ as part of the peptide backbone.

2.7 Living systems as analogs of topological quantum computers

Topological quantum computation (TQC) has in the TGD framework a realization in terms of braids realized as magnetic flux tubes connecting subsystems [K10, K9, K18]. The flux tubes carry $h_{eff} = nh_0$ phases of ordinary matter behaving in many respects like dark matter. In living matter TQC-like activities would be realized in several scales associated with the hierarchy defined by the levels of MB and one can even speculate that TGD is the basic function of living matter. This motivates a brief comparison of TGD based view about quantum computation (QC) and TQC with the standard view.

2.7.1 Basic distinctions from the standard view

The TGD based view about quantum computation (QC) [K10, K9, K18] differs in several aspects from the standard view.

1. The hierarchy of Planck constants makes it possible scal the time and spatial scales of QC by realizing it using dark matter as $h_{eff} = nh_0$ as phases for ordinary matter. This is possible at quantum criticality in which long range correlations associated with quantum fluctuations are realized as $h_{eff} = nh_0$ phases, which play a crucial role in the living matter. What is favorable for QC is that for large values of h_{eff} dissipation rate is small.

2. The fragility of quantum entanglement is a basic problem of standard QCD. Partially it is due to the smallness of Planck constant. Number theoretic vision predicts that one can assign to quantum entanglement ordinary entanglement entropy and also p-adic entanglement entropy which is possible if entanglement probabilities belong to the extension of rationals assigned to the space-time region considered. $h_{eff}/h_0 = n$ corresponds to the dimension of extension associated with the space-time surface and is determined by the degree of the polynomial determining it at the level of $M^9 8$ ($M^8 - H$ duality). Negentropy Maximization Principle

(NMP) is the basic principle of TGD inspired theory of consciousness as a generalization of quantum measurement theory based on zero energy ontology (ZEO).

The prediction is that the quantum entanglement associated with entanglement with positive p-adic entanglement negentropies is very stable and the negentropy of the entire system tends to increase. This implies evolution as an increase of algebraic complexity accompanied by the increase of h_{eff} and quantum coherence scales.

3. Negentropic quantum entanglement favored by NMP satisfies strong constraints. In particular, the entanglement probabilities are rational numbers. Therefore this kind of entanglement is very rare. This solves a second basic problem of QC: there are quite too many possible quantum entanglements so that combinatorial explosion is unavoidable.

4. ZEO [L10, L18] [K20] allows also QCs in both time directions. In "big" state function reduction (BSFR) the computation halts and the arrow of time is changed and QC in the opposite time direction begins. At the human level the wake-sleep cycle corresponds to the periods separated by BSFRs. The saying that problems are solved, by sleeping over night, makes sense at a deeper level. During this period dissipation looks like self-organization and regeneration of structures, healing, and biological systems would apply this mechanism in all scales in order to fight against second law. One can also ask whether QC forth-and-back in time could make QC much faster.

2.7.2 TQC in the TGD framework

TQC is a very natural option in the TGD framework [K10, K9, K18]. The basic notions are magnetic body (MB) having magnetic flux tubes and flux sheets as body parts and dark matter residing at MB.

1. ZEO replaces 3-D quantum states with superpositions of deterministic time evolutions as preferred extremals (PEs) of the basic action principle, and are analogous to Bohr orbits and realize almost ideal holography - required by the realization of general coordinate invariance, in the sense that 3-D data fix the entire 4-surface. PEs are analogous to biological functions, behavior patterns in neuroscience, and computer programs in computer science. SFRs as acts of free will replaced these programs with new ones.

   PEs would be 4-D minimal surfaces with singularities of lower dimension. PE is analogous to soap film spanned by frames defining the singularities. As in the case of soap films, the frames give rise to a finite failure of strict determinism and ideal holography. This failure would be a classical space-time correlate for quantum non-determinism, or at least what I have called cognitive non-determinism as a correlate for imagination.

   In purely classical physics holography is not realized. It is easy to understand this by thinking in terms of a point-like particle (for which 3-surface is a generalization). A particle at a given point can go in any direction with any velocity. By ideal holography only single direction and unique velocity is allowed.

2. Magnetic flux tubes connecting 3-surfaces give rise to networks. 3-surfaces appear as nodes of this network. An interesting possibility is that these 3-surfaces have as a good approximation 2-D projection to 3-space and therefore define membrane-like objects. All membrane like objects, such as cell membrane could be associated with this kind of 4-surfaces.

   The flux tube connections are a new element not present in the standard physics. The flux tubes can be idealized as string-like entities. In 3-D space the flux tubes can get knotted and linked with each other and define in this way braids - or rather, generalizations of braids. They would define the topological space-time correlate for a TQC program,

3. Fermionic degrees of freedom (quarks at fundamental level giving rise to all elementary particles including bosons and also leptons as the bound states) define the fermionic part of TQC. Fermionic states reside at the ends of braids at the nodes of the network and more generally at the 3-surfaces from which the flux tubes begin.

An important delicacy, forced by the fact that flux tubes carry monopole flux, is that flux tubes associated with a 3-surface are tentacle-like U-shaped flux loops, and their reconnection builds flux tube pairs connecting 3-surfaces.

4. Reconnection for U-shaped flux tubes for a pair A,B of nodes forms a flux tube pair connecting A and B. The reversal of this process destroys the flux tube connection. If all flux tube connections from subsystem A to the environment disappear, A de-entangles. Thus it seems that the presence of flux tube pairs makes possible entanglement. The change of entanglement in turn has braiding as a space-time correlate.

   The halting of TQC assignable to subsystems could correspond to the de-reconnection process for a subsystem. Partial de-reconnection is also possible and the notion of partial halting might make sense.

   The braids are effectively 1-D and their time evolution defines effectively 2-D surfaces inside a 4-D space-time surface. They can form 2-knots as a generalization of ordinary knots which are 1-knots. The reconnection processes define the topology of these 2-knots. For higher-D space-time surface 2-knotting is not possible so that from the point of view of TQC, the dimension D=4 for the space-time is completely unique as also the dimension D=3 for 3-space.

5. Dance metaphor [K10, K9, K18] is a highly useful way to see TQC in the TGD framework. One can think that the nodes of the network are like dances connected to each other by thin threads. Dancers change their partners and define a complex pattern on the dance floor. At the space-time level this defines braiding of the time-lines of the dancers. One can speak of a time-like braid.

   Also the threads connecting the dancers are braided and form space-like braind determined completely by the time-like braiding once the initial state of the space-like braid is fixed. This is not quite the case if reconnections splitting or creating threads between dancers take place. One can say that the space-like braiding records the history of the dance hall as analog of akashic records. One can also speak of topological memory.

6. The evolution of the entire TGD Universe can be regarded as a fractal hierarchy of TQCs based on the fractal hierarchy of magnetic flux tubes characterized by algebraic extensions of rationals to which one can assign p-adic primes as maximal ramified primes. These in term define p-adic length scales assignable to the flux tubes. The braiding of flux tubes takes place in all scales. For instance, while moving around, we contribute to a generation of this kind of braids defining analogs of TQCs.

Biochemistry could represent especially refined analog of TQC. The basic notions of biochemistry interpreted in TGD framework correspond to those of TQC according to TGD as described above but also some new elements emerge.

1. Consider the TGD inspired view about bio-catalysis [L28]. Reconnection is the basic mechanism of bio-catalysis. According to the TGD based view about bio-catalysis, reactants find each other by using as tentacles U-shaped flux tubes and resonance mechanism.

   Flux tubes can touch but this is not enough. There must be a resonance. This occurs if the cyclotron frequencies associated with the flux tubes are identical. This is possible if the flux tubes have the same radius and therefore identical magnetic field strengths and cyclotron frequencies.

   If the value of h_{eff} associated with the flux tubes is reduced, the pair is shortened and forces the reactants near each other. The reduction of h_{eff} liberates energy, which in turn makes it possible to overcome the potential wall, which otherwise prevents the reaction from occurring. After the reaction the energy needed to overcome the wall is liberated and can bring U-shaped flux tubes to its original size. Note that the values of h_{eff} tend to be reduced and metabolic energy feed is to provide the energy needed to preserve the distribution of h_{eff} values.

   Since reconnection takes place and reaction can produce new nodes, biochemical reactions do not reduce to the notion of gate in the generalized view of TQC.

2. Besides reconnection, the notion of tuning is also fundamental and brings a new element to TQC according to TGD. The change of the thickness of the flux tube as the basic motor action of the flux tube (besides reconnection and contraction) changes the cyclotron frequency. The frequency modulation makes it possible for flux tubes to search whether some objects are present in the environment. This would be the basic operation of the immune system at quantum level [K3] [L26]. The tuning of the flux tubes of MBs of the water clusters makes it possible for them to mimic the cyclotron spectrum of invader molecules and this ability explains water memory.

3. Bioharmony [L2] [L13, L17, L27] is a further TGD based notion. The proposal is that genetic code has two quantum realizations. The first one is based on dark nucleon sequences with a dark codon realized as a nucleon triplet. For the second realization codon corresponds to dark photon triplet. These triplets behave like quantum coherent units and are analogous to quarks as 3-quark bound states.

   The binding mechanism is purely number theoretic and universal. Also genes can be regarded as dark 3N-nucleons or 3N-photons. The states of dark proton triplets correspond to all basic biomolecules DNA- ,RNA-, and tRNA-codons, as wella s amino acids (AAs).

   Bioharmony defines the dark photon realization of genetic code. Communications occur by using 3-chords (or possibly even 3N-chords). The ordinary resonance between participants with the same value of h_{eff} is replaced with 3N-resonance. The allowed 64 3-chords define bio-harmony as a collection of allowed 3-chords. Music expresses and creates emotions and the natural interpretation is that bioharmony is assigned to variants of genetic code which correspond to different molecular moods. Also the energy resonant communications between dark and ordinary variants of codons must be possible and this poses extremely stringent conditions on the basic bio-molecules.

   Bioharmony realizes genetic code and would become the basic code of TQC. Codons or even their sequences would serve as addresses. The signal is a sequence of these 3-chords, analog for a piece of music, and is received by resonance mechanism only by receivers which correspond to a sequence of dark nucleon triplets defining the same codons. Note that also partial resonance is possible in which case the number of possible receivers is higher. The principle is the same as in LISP. The message can be coded to the modulation of the frequency scale of chords. The cyclotron resonance peaks define a sequence of pulses making it possible to interpret the message. Nerve pulse pattern could be induced by this kind of pulse sequence.

3 Update of the TGD based view of nervous system

The existing TGD based view of the nervous system will be summarized first. After that the basic notions and the ideas about what happens in nerve pulse conduction are sharpened by using the quantum gravitational view about metabolism. Also the relationship between biochemistry and TGD view about quantum biology will be discussed and lead to highly non-trivial insights about the role of the basic biomolecules.

3.1 The recent TGD based view of nervous system

The proposal [K6, K1, K7, L14] is that the cell membrane possesses a pre-NS based on cell membranes acting as generalized Josephson junctions.

1. The oscillations of membrane potential induce Josephson oscillations as soliton sequences, which represent the ground state of the axon, and possibly also of cilium. A sequence of rotating mathematical penduli in different phases giving rise to a wave is a good analogy. Pre-nerve pulse would correspond to a perturbation of the soliton sequence in which some penduli oscillate instead of rotating, which propagates with the same velocity as the soliton sequence.

   One can also consider an alternative scenario in which the roles of rotation and oscillation are changed. The soliton sequence requires more metabolic energy than its oscillatory counterpart and one might argue that the latter is more favored for this reason.

2. Generalized Josephson radiation gives rise to sensory communications from the cell membrane to its MB using frequency modulated generalized Josephson radiation with generalized Josephson frequencies $f_J = E_c/h_{eff}$ (and their multiples), which correspond to the energies $E_J = \Delta E_c + ZeV$, where ΔE_c is the difference of cyclotron energies for flux tubes at different side of membrane, and ZeV is the usual Josephson energy. Z denotes the charge of a Cooper pair or bosonic ion. For $h_{eff} = h_{gr}$ the generalized frequencies are in EEG range and nerve pulses appear as frequency modulations of the generalized Josephson frequencies.

3. The frequency modulated generalized Josephson radiation is received at MB and induces pulse by cyclotron resonance defining the response of MB as a dark cyclotron radiation. The response of MB corresponds to a sequence of resonance peaks, which induce pre-nerve pulses as propagating perturbations of the soliton sequence. The perturbation would change the rotating motion of the effective gravitational pendulum to an oscillating motion.

   The pre-nerve pulse induces a nerve pulse if a quantum criticality condition stating that the magnitude of the resting potential is above the critical value is satisfied. Synaptic transmission builds a contact between pre- and postsynaptic cells and connects U-shaped flux tubes parallel to the dendrites and axon to a pair of flux tubes.

Which part of the neuron could receive the response of MB?

1. The original proposal [K6] was that the response of MB occurs directly at the level of the genome. This would require a network of flux tubes connecting cell nucleus and cell membrane transmitting the response from genome to cell membrane. This flux tube network would also make topological quantum computation-like processes possible [K9, K18].

2. One can also imagine a simpler scenario. The response would be received by the cell membrane and generate second messenger molecules, which carry a chemical signal to the cell nucleus. The response could be seen as a sensory communication with a reversed arrow of time. The objection is that sensory and motor systems are different for vertebrates. One can however argue that the time reversal is for the combined system. If sensory and motor sub-systems have opposite arrows of time, only either of them contributes to "our" conscious experience at once.

   Interestingly,in human EEG there is a clear division into quasi-stationary periods with a duration of about .3 seconds [J2] discussed from the TGD point of view in [L1]. The first half of the period looks ordered and the second half chaotic. I have proposed that these pieces are separated by BSFR at MB as a response of MB and correspond to different arrows of time.

Synaptic transmission is second key part of neural activity.

1. Synaptic transmission involves the transmission of a bag of neural transmitters implying that the pre- and post-synaptic cell membranes touch and fuse to a singly entity temporarily. This would imply also the fusion of the magnetic flux tubes assignable to pre- and postsynaptic axons to a single flux tube and make possible both the transfer of quantum coherence and the propagation of dark photon signals assignable to magnetic flux tubes acting as wave guides. The flux tubes could be called pre-axons.

2. The deeper function of neurotransmitters remains a mystery in the framework of the standard neuroscience but terms like reward and punishment are routinely used. In the TGD framework, these terms could be more than convenient metaphors.

   The neurotransmitters arriving in the synaptic contact could induce a change of the local bioharmony and thus a change of the local mood so that the heuristic terminology would be justified. At the level of the basic biomolecules the epigenetic regulation based on methylation could induce similar changes [L27]. The decision making of neurons would rely on emotions created by various synaptic inputs: this is the situation also at our level!

Axonal MTs could make the conduction of nerve pulses through the myelinated portions of the axon possible. Inside myelinated portions the transfer of ions between interior and exterior of the

axonal membrane is not possible. The shortening of axonal MTs involves localization of delocalized protons and electrons at gravitational flux tubes and changes the charge of the axonal interior and this in turn can take the membrane potential below the critical value and make the conduction possible. Note however that the drop of electrons and protons would take place at Bohr orbit with Earth radius. A further localization to atomic level would liberate more energy.

3.2 Clarification of some basic concepts

In the following I try to further clarify the basic notions used in order to identify the weaknesses of the scenario.

3.2.1 About the notion of dark ion

The original view was that dark ion as a whole resides at the flux tube. Later this statement became more precices: dark ion is touches the , say gravitational, dark flux tube with $h_{eff} > h$. This applies also to both gravitational, electromagnetic, weak, and color flux tubes and ordinary bonds correspond to electromagnetic flux tubes with $h_{eff} = h_{em}$ [L5].

The entire dark ion touching the flux tube would have wave function in the magnetic field of flux tube having the touching point as argument. Cyclotron states are natural.

The more precise view considered already earlier is that one has effective ion: the dark elecron or Cooper pair resides at gravitational flux tube is not bound to the atom as effective ion. The predictions for dark cyclotron states are same as for the older picture and the predictions related to the dark electron or proton are new.

3.2.2 About the notion of electric flux quantum

What does one mean the flux tube parallel to axon?

1. I have talked assigned to axon a magnetic flux tube parallel to it and accompanied by magnetic flux tubes transversal to it. This would correspond to a 3-D network of flux tubes.

   The problem has been how to describe the membrane structure with electric field and electric flux orthogonal to the flux tube. This situation requires genuine electric flux quanta analogous to magnetic flux quanta and the time dependent deformations of the magnetic flux tube cannot give them. However, magnetic flux tubes allow very simple time dependent deformations allowing longitudinal electric flux along the tube.

2. Could electric flux quanta associated with a pair of lipid layers correspond to a pair of membrane-like objects having 1+2-D rather than 4-D M^4 projection connected by time-dependent deformations of transversal magnetic flux tubes carrying a longitudinal electric field?

3. Unfortunateluy, I did not have any candidate for an explicit solution of field equations describing 2-D membrane-like object such as cell body or axon. For some time ago I finally understood 2-D membrane-like objects in terms of 3+1-D minimal surfaces in $H = M^4 \times CP_2$.

   M^4 projection is 3-D and E^3 projection 2-D membrane. The basic problem is posed by the fact that 2-D closed minimal surfaces are not possible. For soap bubbles a pressure difference over the soap bubble is required and one loses minimal surface property. The solution of the problem was that the 1-D CP_2 projection of the surface is dynamical and allows 4-D minimal surface. The simplest option is that it represents rotating geodesic circle.

4. Therefore one can ask whether lipid bilayer could have pair of electric bodies (EBs) serving for them as a kind of template and connected by transversal elecric flux tubes carrying a longitudinal rather than transversal electric field.

3.3 Gravitationally dark effective ions

Besides organic molecules but also metal ions are fundamental for metabolism and bio-catalysis. This led to the TGD inspired proposal that they give rise to dark ions and the recent work gives further support for the view is that gravitationally dark electrons given them their special role

1. Various bosonic effective metal ions and their Cooper pairs can get paired by gravitational flux tube with atoms of opposite total valence. The distance between paired system can become due the relative motion of the atoms considered. Also reconnections of gravitational flux tubes could cause this.

   Correlations are predicted between the members of pairs. The presence of gravitational hydrogen- and valence bonds (VBs) implying the presence of effectiove ions could distinguish biochemistry from chemistry. Also electrolysis, and therefore organic chemistry in general, involves the ionization of atoms very difficult to understand without the notion of dark gravitational valence- and hydrogen bonds. Also the physics of water is full of thermodynamical anomalies suggesting the presence of these bonds.

2. According to standard chemistry, one has equilibrium $X(OH)_2 \leftrightarrow X^{++} + 2OH^-$ for X$\in$ {Ca, Mg, Fe} in water environment. Gravitational effective ionization effectively breaks charge conservation and one would obtain quantum correlated pairs formed from X^{++} connected by flux tubes H_2O_2. Gravitationally dark electrons would not be visible. This would mean apparent charge non-conservation, which could be tested as deviation of the concentrations from the prediction $n(X^{++}) = 2n(OH^-)$.

   This could happen also for water itself. $H_3\ O)^+$ and OH^- ions are present. OH is not stable but the pairing $2(H_3\ O)^+ + 2H_2O_2$ by gravitational hydrogen bonds is possible. Also H_2O + OH^- pairs with one dark gravitational proton are possible. The concentrations of $(H_3\ O)^+$ and OH^- would be different.

3.3.1 Signatures of dark effective ions

The ions X^{++}, X $\in$ {Ca,Mg, Fe,Z} and X $\in$ {Li, Na, K} would be actually effective ions with gravitationally dark VBs. Dark effective ions have special signatures, which allow to test the TGD view.

1. These effective ions effectively break charge conservation. Is the transformation of $X(OH)_2$ $\rightarrow X^{++} + H_2\ O_2$ rather than $X(OH)_2 \rightarrow X^{++} + 2OH^-$ in question as would be if electrons become gravitationally dark. Note that hydrogen peroxide $H_2\ O_2$ is a reactive oxygen species (ROS) (`https://cutt.ly/NFima6X`) playing a very important role in biology. ROS are produced in biological processes, in particular metabolic process such as respiration and photosynthesis. TGD view would mean that ROS are not a nuisance but an essential element of electron based metabolism.

   For X^+, X $\in$ {Li, Na, K} the electrons of the Cooper pair are paired with two OHs. Two XOHs forms Cooper pair of X^+:s correlated hydrogen peroxide H_2O_2. This would represent new physics and effective charge non-conservation.

2. Quantum gravitational correlations between H_2O_2 and X^{++}, X $\in$ {Ca, Mg, Fe, Zn} and between H_2O_2 and Cooper pars of X^+, X $\in$ {Li, Na, K} are predicted and this prediction might be testable.

3.3.2 Some facts about Calcium ions

Basic facts about Ca ions allow to get idea about the implications of new metabolic quantum and the quantum gravitational realization of metabolic energy quanta.

1. Calcium ions (Ca^{++}) contribute to the physiology and biochemistry of organisms' cells. They play an important role in signal transduction pathways, where they act as a second messenger, in neurotransmitter release from neurons, in contraction of all muscle cell types, and in fertilization.

2. Calcium phosphate `https://cutt.ly/4FimgMc` appearing in bones combines effective ions possibly having gravitationally dark protons and electrons (Calcium phosphate is also considered in [L15]). Posner molecule $[(PO_4)^{-3})]_6Ca_9^{+2}$ made of 6 phosphate ions and 9 calcium ions would be the key player and has been proposed to play central role in consciousness theory [J5, J8] (`https://cutt.ly/bFimzit`). I already mentioned Posner molecules and a

possible realization of genetic code using dark Cooper pairs of electrons. I have considered Posner molecules from the TGD point of view in [L4].

3. Ca^{++} currents initiate action potentials. Voltage gated Ca^{++} channels emerge first in the maturing of neuron and also in evolution of nervous system (already monocellular eukariotes generate action potentials). Na^{+} channels emerge later. The action potentials pulses have a longer dead time for Ca^{++} than for Na^{+}.

   For instance, Ca^{++} initiates a contraction of muscle and helps to maintain the potential difference over cell membrane, which conforms with the proposed role in electronic metabolism.

4. Ca^{++} appears as a second messanger molecule. The TGD view about second messanger molecules is discussed in [L25]. Cell interior, in particular mitochondria and endoplasmic membranes contain storages of Ca^{++}. Mitochondria would thus involve both forms of metabolism.

3.3.3 Ca^{++} waves

Ca^{++} waves could be effective ions due to gravitationally dark Cooper pairs.

1. Ca^{++} waves are very important in biology and appear in cell interior and between cells. A calcium wave is defined as a localized increase in cytosolic Ca^{++} that is followed by a succession of similar events in a wave-like fashion. Ca^{++} waves can be restricted to one cell (intracellular) or transmitted to neighboring cells (intercellular).

2. Calcium waves are also associated with glial cells. Ca^{++} waves are of special importance in astrocytes and other glial cells [J7]. This should relate to electronic metabolism of the primary cilia associated with both neurons and glial cells.

   Calcium waves and miniature potentials would naturally relate to dark electron metabolism. Both glial cells [J4] and neurons [J3] have primary cilia acting as sensory receptors and since cilia cannot use ATP metabolis, electronic metabolism is natural.

3.4 About the model for the nerve pulse

Could one construct a simplified TGD based model for the nerve pulse [K6] using this kind of picture utilizing holography meaning that one can take the EBs as basic objects to which one can assign densities of various ions atoms and normal components of electric field as charge densities? Can one decompose these densities to various contribution assignable to ions or effective ions?

The basic physical picture would be as follows. The transformation of the pairs of metal atom with atoms with total valence equal to that of metal would generate gravitationally dark metal atoms, which are effective ions which correlate with the paired atoms. The valence charge of the metal atom effectively disappears and implies an effective charge non-conservation. In nerve pulse these effective ions would disappear and would look like charge non-conservation. Also effective ionic currents appear.

1. Josephson currents are assumed to flow along dark flux tubes connecting the two systems and electric field would be along them. Gravitationally dark protons and electrons reside at gravitational flux tubes as very long loops connecting cell interior and exterior. Dark ions are associated with these flux tubes (touch them).

2. What kind of dark Josephson currents could flow along them? If the two atoms are localized at the ends pf the dark gravitational valence- of hydrogen bond at the opposite sites of the membrane, the dark electron and proton Josephson currents can run along gravitational flux tube. Also effective dark ion currents can flow between interior and exterior since the gravitational VB with H_2O_2 can get stretched.

   Gravitational flux tubes assignable to valence and hydrogen would connect systems such as X^{++}, X$\in$ Ca, Mg, Fe and hydrogen peroxide H_2O_2, which is a reactive oxygen species (ROS). The currents would flow between systems containing these dark ions and molecules.

3. More than 100 miniature potentials induced by Ach vesicles are needed to initiate nerve pulse in synaptic contact. The miniature potential corresponds to a liberation gravitational electronic metabolic quantum as a transformation of gravitationally dark electron to ordinary one. This critical reduction of membrane potential would induce the reduction of the membrane potential below the critical value and induce the action potential. Also protonic metabolic quanta are involved and would relate to the ordinary metabolism based on ATP machinery.

The TGD picture challenges the Hodgkin-Huxley model of nerve pulse generation (`https://cutt.ly/FFiWTNA`). The model for the neuronal membrane assumes that ohmic currents flow through the ion channels. What happens when a Ca^{++} initiated action potential is generated?

1. The standard description using Hodgkin-Huxley model is in terms of a rush of Ca^{++} ions to the cell interior along Ca^{++} channels. The process occurs spontaneously since the cell interior is negatively charged and does not require metabolic energy. These currents would be ohmic and dissipative. This description could make sense only in the non-myelinated portions of the axons.

   Since only non-dissipative Josephson currents for dark Ca^{++} ions are possible, the rush of dark Ca^{++} dark ions does not seem plausible in the TGD picture. However, the delocalized electronic charge could end up to the hydrogen peroxide H_2O_2 paired with Ca and a genuine Ca_{++} ions would be created. The same applies to Cooper pairs of other dark metallic ions. In the myelinated portions of axon this kind of mechanism could work so that the Hodgkin-Huxley model would describe the situation.

   Inside the myelinated portions of the axon, the transformation of gravitationally dark protons to ordinary protons would reduce the associated effective negative charge and make membrane potential more positive and take it below the critical value for nerve pulse generation at non-myelinated portions.

   Also pairs of dark Ca^{++} ions and dark H_2O_2 pairs from $Ca(OH)_2$ can be created, perhaps by a double (effective) ionization creating pairs of dark Ca^{++} ions and dark H_2O_2 pairs from $Ca(OH)_2$ in an electric field in the cell interior. Also dark gravitational VBs associated with Ca would be created in the cell interior and dark electron Josephson currents would be generated. The charge densities inside and/and outside the neuronal membrane would change and affect the membrane potential. This option could be realized in the non-myelinated sections of the axon in the resting state: nerve pulse would involve a transformation of dark ions to ordinary ones.

2. What looks very strange from the TGD point of view is that, although the generation of nerve pulse is spontaneous and is therefore expected to reduce the value h_{gr}, which in turn would liberate energy identified as a metabolic energy, just the opposite occurs. Can one conclude that a BSFR occurs at critical membrane potential and the arrow of time is changed. In this situation the process would be dissipative but in a reversed time direction. Later support for this interpretation will be found.

This raises a question considered from the TGD point of view in [K5]. Do the ion channels and pumps really act as channels for ionic currents or can only electronic, protonic and ionic Josephson currents flow through them?

1. The experimental work of Ling, Sachs and Qin [I9, I16] and other pioneers [I7, I4] challenges the notions of ionic channels and pumps central to the standard cell biology. Ling has demonstrated that the ionic concentrations of a metabolically deprived cell are not changed at all: this challenges the notion of cell membrane ionic pumps.

2. The work of Sachs and Qin and others based on patch-clamp technique shows that the quantal ionic currents through the cell membrane remain essentially as such when the membrane is replaced by a silicon rubber membrane or by a cell membrane purified from channel proteins! This challenges the notion of cell membrane ionic channels. A further puzzling observation is much more mundane: an ordinary hamburger contains roughly 80 per cent of water and is thus like a wet sponge: why is it so difficult to get the water out of it?

Membrane potential changes sign during the nerve pulse. The interpretation as a BSFR changing the arrow of time is suggestive and the above observation suggests the same?

1. If the action potential corresponds to two subsequent BSFRs as a kind of quantum tunneling event, the arrow of time temporarily changes at MB and changes the effective arrow of time at the level of the ordinary biomatter. Gel-sol phase transition in the neuron interior near neuronal membrane signals about the reduction of the quantum coherence scale.

2. The TGD based description for the change of the sign of the membrane potential is in terms of the model of nerve pulse describing the ground state as a soliton/oscillon sequence and mathematically equivalent to a sequence of gravitational penduli rotating/oscillating in synchrony. Can one choose between these options?

   Critical membrane potential would correspond to a situation in which the rotation changes to oscillation or vice versa. The fact that the membrane potential changes sign and has original magnitude, supports the soliton model. The rotation frequency would transform to a vibration frequency, decrease further, change sign and eventually transform to a negative rotation frequency. The arrow of time would have changed. The reverse of this process would correspond to the second BSFR leading to hyperpolarization.

3.5 Microtubular level

TGD predicts two forms of metabolism [L24]. The ordinary metabolism relies on gravitationally dark protons originating from hydrogen bonds. For the new form of metabolism dark protons are replaced with gravitationally dark electrons or their Cooper pairs originating from metal atoms. Both dark electrons and dark electron Cooper reside at gravitational Bohr orbits with the same spectrum of radii. When they transform back to ordinary particles, they become gravitational Bohr orbits at distance defined by Earth radius and therefore liberate energy.

This metabolic mechanism could be associated with cilia and flagella having no mitochondria in their interior and could be also important in the metabolism of axonal MTs.

3.5.1 Could the metabolism of cilia and flagella rely on gravitationally dark electrons?

The recent work in TGD has led to considerable progress in the understanding of metabolism [L24] already discussed in the section 2.5. The TGD based view about metabolism involves in an essential way quantum gravity.

The observation is that the gravitational binding energy of dark protons at Bohr orbits in Earth's gravitational field for $h_{eff} = h_{gr} = Gmm/v_0$ [E1] [K14, K17] [L21, L16] can correspond to metabolic energy quantum in good approximation. The proposal is that the transformation of protons of hydrogen bonds possible for electronegative atoms and occurring at least for phosphate generates gravitationally dark protons. Their transformation would liberate metabolic energy quantum.

The prediction is that besides gravitationally dark protons also similar electrons define a metabolic energy currency relating to standard metabolic currency like cent to dollar. It is proposed that the electronic metabolic currency can be applied to the purely understood metabolism of cilia and flagella (`https://cutt.ly/WDkYZzx`). I attach the proposal below almost as such.

According to [I18] (`https://cutt.ly/EDkW2bu`) the recent measurements in sea urchin sperm (length ~ 50 μm long, diameter 0.2 μm) show that the energy consumed per flagellar beat corresponds to $\simeq 2 \times 10^5$ ATP molecules. There is no GTP inside cilium as in the case of axonal MTs (`https://cutt.ly/5DkYGB2`). It is difficult to understand how ATP machinery could provide the metabolic energy feed.

This motivates the question about whether local ciliary metabolism could rely on the transformation of valence electrons of some biologically important ions to dark electrons at the gravitational MB and vice versa? The reduction of h_{gr} for electrons would provide the metabolic energy related by a factor $m_e/m_p \simeq 2^{-11}$ to the ordinary. According [I18], about 4×10^8 gravitationally dark electrons would transform to ordinary ones in a single stroke of cilium.

Electronic metabolic energy quantum would relate like cent to dollar and make possible a more refined metabolism with fine tuning. Electronic metabolism could also be an essential part of ordinary metabolism.

Consider now the idea more quantitatively.

1. What could be the electronic analog of ATP machinery. All biologically important ions can be considered as effective ions with some valence electrons at gravitational MB. In particular, the bosonic ions Ca^{++}, Mg^{++}, Fe^{++} and Zn^{++} could have Bose-Einstein condensates of gravitationally dark Cooper pairs at the gravitational MB.

   Ca^{++} waves play a key role in cellular biology, Fe^{++} is essential for oxygen based metabolism, and Mg^{++} and Zn^{++} are important in bio-catalysis: for instance, ATP must bind to Mg ions in order to become active.

2. What could be the mechanism transforming valence electrons to dark electrons? This should happen for positively charged biologically important ions, in particular for the bosonic ions Ca^{++}, Mg^{++}, Fe^{++} and Zn^{++}. The consumption of metabolic energy would correspond to a de-ionization of dark ion Ca^{++} and this might make it possible to test the proposal. For instance, Ca^{++} could accompany ciliary waves.

Where could the energy for ionization come from?

1. This question is also encountered in the chemistry of electrolytes [L5]. It is very difficult to understand how the external electromagnetic potentials, which give rise to extremely weak electric fields in atomic scales, could lead to ionization. The acceleration of electrons in the electric field along dark flux tubes involves very small dissipation and can easily give rise to electron energies making ionization possible.

2. MTs have a longitudinal electric field which by the generalization of Maxwell's equations to many-sheeted space-time (in stationary situation potential difference is same for paths along different space-time sheets) gives rise to an electric field along the magnetic flux tubes. These flux tubes need not be gravitational.

   By darkness, the dissipation rate is low. Could the acceleration along flux tubes, in particular MT flux tubes, lead to the ionization? Could the electret property of linear biomolecules quite generally serve for the purpose of generating electronic metabolic energy storages in this way?

3. Assuming opposite charges $\pm Z_{MT}$ at the ends of dark magnetic flux tube associated with the MT, one obtains a rough estimate. The length of the cilium is $L \leq .5 \times 10^{-4}$ m and its radius is $R \sim 2 \times 10^{-7}$ m. The estimate for the energy gained by a unit charge e as it travels through the ciliary MT is $E \sim Z_{MT} e^2 L/R^2 \simeq Z_{MT} \times 2.85$ eV. The valence electron energy for atomic number Z with principal quantum number n (giving the row of the Periodic Table) is $E \simeq (Z/n)^2 \times 13.6$ eV. The ionization condition would be $Z_{MT} \geq (Z^2/n^2) \times 13.6/2.85$. For the double ionization in the case of Ca^{++} with $Z = 20$ and $n = 3$ this would give $Z_{MT} \geq 212$.

3.5.2 TGD based view about axonal and cellular microtubules

Axonal MTs and also subset of MTs in the cell body are highly dynamical critical systems changing their length continually. It seems that they are essential motor instruments of MB just like the MTs of motor cilia. Could the microtubular structures in cell soma are also analogous to supporting structures which can be rapidly deformed by making them unstable against the change of length.

1. Instability of axonal MTs and nerve pulse conduction

In the TGD framework, axonal MTs could make nerve pulse conduction in the myelinated portions of axons possible. The localization of dark proton charges in the shortening flux tube would change the charge of the MT interior and in this way affect the local membrane potential and bring it to criticality. Time reversal and BSFR could be associated with the change of the growth of the MT length to decrease or vice versa. The lengthening and shortening processes would be the same but have different arrows of time. The propagation of the wave at which arrow of time for MT changes would correlate with the conduction of nerve pulse.

The dynamic instability of the axonal and some cellular MTs (https://cutt.ly/ADzx3re) is not well-understood. Power stroke causing the decay of the MT at its end is the basic notion. Whether chemical action precedes the mechanical one or vice versa is not clear. Therefore an obvious question is whether chemistry and mechanics are enough. The following represent a possible TGD based view about the power stroke.

1. Gravitationally dark proton transforms to ordinary proton of a phosphate hydrogen bond in the transformation of GTP to GDP. This liberates metabolic energy quantum, serving as a power stroke. This localizes one unit of proton charge and in this manner affects membrane potential.

2. Assume that MT is associated with a cylindrical membrane, that is 4-D minimal surface with 3-D M^4 projection having no counterpart in GRT. M^4 projection would have the microtubular cylinder as an E^3 projection. Cylinder is not a minimal surface and the cylindrical analog of the soap bubble requires a pressure difference over the cylinder walls.

   In the TGD framework, CP_2 projection as a dynamical 1-D curve, say rotating geodesic line of CP_2 would give rise to the effective pressure difference [L23]. This analog of pressure difference would increase in the power stroke and locally expand the cylinder at the position of GDP. This would push tubulin protein outwards. These kinds of power strokes would force the MT to decay and shorten.

2. Energetics of the axonal transport

The transfer of material along the MT is the basic motor activity of MTs (https://cutt.ly/TDzOePw). The transfer of protein cargoes is a very slow process even on human time scales. Therefore these processes could involve electron (Cooper pair) based metabolism in an essential way. Note however that mitochondria are present also inside MTs.

If electronic metabolism is in question, these processes are predicted to be much slower than those induced by protonic metabolic currency since the work $F\Delta x$ done by the force corresponds to metabolic energy quantum and for Δx about tubulin size, F smaller by a factor m_e/m_p than in the case of protonic metabolic quantum.

3.5.3 Delayed luminescence for microtubules,quantum gravitation, and the mechanism of anesthesia

Jack Tuszynksi has reported very interesting findings in Science of Consciousness 2022 (https://cutt.ly/PF6OcxA). The findings are described in a popular article (https://cutt.ly/tF6OhWz).

A delayed luminescence in microtubules (MTs) irradiated by laser light has been observed. This can be seen as a support for the presence of quantum coherence at least in the scale of MTs. Also it was found that the application of anesthetics (such as noble gas Xenon expected to have very weak chemical effects) shortens the delay time. This suggests the reduction of quantum coherence by anesthetics so that quantum coherence in long scales should be crucial for consciousness. One of the challenges is to understand the reason for the reduction of quantum coherence.

Delayed luminescence has been associated with bio-photons a long time ago and DNA is proposed to serve as the seat of the delayed luminescence. In particular, the group involving also Tuszynski has studied the emission of mitochondrial biophotons and their effect on electrical activity of the membrane via MTs [J6] (https://cutt.ly/XF6OqLA). A TGD based view of biophotons as decay products of dark photons is discussed in [K8, K12].

To my opinion, the findings represented by Tuszynski provide support for quantum consciousness but not specifically for Orch-OR, which still remains a rather poorly defined approach since the statement that Planck scale quantum gravity effects are crucial for consciousness has no concrete content.

The TGD based interpretation of findings of Tuszynski would be as follows.

1. The laser beam serves as a metabolic energy feed increasing the value of h_{eff} and therefore the scale of quantum coherence. One can say that this metabolic energy feed creates or wakes up an analog of a conscious living organism: now at the level of microtubule MB. As it "dies"

in "big" state function reduction (BSFR) involving the reduction of h_{eff} to a smaller value, not necessarily the normal value $h_{eff} = h$, the loaded metabolic energy is liberated.

This would not apply only to MTs but quite generally. For instance, biophoton emission from cut leaves, would represent a similar decay process. Biophotons would be ordinary photons resulting as decay products of dark photon BE condensates and dark photons emitted with cyclotron Bose-Einstein condensates decay.

2. The delocalization mechanism associated with the formation of the gravitational variants of hydrogen- and valence bonds allows effective charge densities in short scales and could have dramatic implications for the model of nerve pulse. The nerve pulse need not correspond to a generation of ohmic currents through the membrane but to effective ionization or its reverse process due to the transformation of hydrogen and valence bonds to dark gravitational bonds.

3. MTs could play an important role since they involve GTPs as analogs of ATPs and are thus involved with metabolism. The conduction of nerve pulse in the sense of the Hodgkin-Huxley model through myelinated sections of axons is very difficult to understand. The new view would allow the shortening and lengthening of MTs to change the effective charge density of MTs so that membrane potential would change and nerve pulse conduction in the TGD sense would be possible.

How could one understand the effect of anesthetics? I have considered this problem earlier. First one should try to understand how the critical dynamics of MTs relates to nerve pulse conduction inside myelinated regions of the axon.

1. Certainly the membrane potential should become hyperpolarized to prevent nerve pulse condition so that consciousness would be lost. In myelinated portions of axons there is only propagating perturbation of membrane potential taking it below the threshold for nerve pulse generation so that nerve pulse is generated at unmyelinated portion. In the ground state one has propagating Sine-Gordon soliton (or oscillon sequence) visualizable as a sequence of rotating (oscillating) gravitational penduli.

   In the perturbation some penduli start to rotate in an opposite direction (or oscillation transforms to a rotation). Usually this would require flow of charge through the cell membrane as Josephson current. Now the variation of the effective charge densities caused by the delocalization of protons inside the axon would induce an effective Josephson current. The effective charge inside the axonal interior becomes less negative and induces at non-myelinated portions of the axon a nerve pulse describable using the Hodgkin-Huxley model.

2. A couple of comments about the arrow of time are in order. Nerve pulse is induced by ~ 200 miniature potentials of amplitude about .4 meV which could be assigned to electron metabolic energy quantum. This corresponds to energy of .8 eV, roughly 2 protonic metabolic energy quanta. This supports an interpretation in terms of a time reversed process in which two metabolic energy quanta decay to ~ 200 miniature potentials. This conforms with the proposal that nerve pulse generation is BSFR inducing time reversal.

   The reconnection transforming HB (VB) to its gravitational variant or vice versa during nerve pulse propagation induces the transfer of proton (electron) to MB. Since the size scale of the gravitational bond is that of Earth, this would take time and could be too slow for protons. The problem disappears if the reconnection corresponds to BSFR changing the arrow of time. The BSFR occurs and the final state is what becomes the causal agent just as in the explanation of Libet's findings about active aspects of consciousness.

3. If the anesthetic induces the transformation of gravitationally dark HBs (VBs) to ordinary ones in the interior of the axon, the effective charge of the axon becomes more (less) negative and the axonal potential becomes more (less) negative. MTs have GTPs near their ends and GDPs in the intermediate region. Negative charges of GTPs and GDPs would naturally correspond to gravitational HBs.

   The variation of MT lengths involves a transformation of GTPs to GDPs and vice versa. This would change the effective charge density of the MTs and affect the membrane potential. If gravitational HBs become ordinary, metabolic energy is liberated and vice versa.

Hyperpolarization would require a generation of reconnections and a local change of the MT lengths.

The variation of the lengths of axonal MTs would induce effective negative charge near the growing end of MT. Could the moving depolarization front of the axonal membrane correspond to an increasing GDP region of an axonal MT?

4. The presence of soliton (oscillon) suggests periodic effective charge density waves in which the protons transform to gravitationally dark protons and vice versa in a periodic manner. Could this mean a periodic variation of the lengths of axonal MTs?

   Also the transformation of metallic valence bonds to their dark variants and vice versa could control the membrane potential. Ca^{++} waves would result in cell interior when valence electron pairs of Ca atoms or their salts become gravitationally dark. Could periodic rotation (oscillation) accompany dark electron metabolism with a much smaller energy cost?

How the presence of noble gas having very weak chemical interactions could affect the nerve pulse conduction inside the axon? One can proceed by making questions.

1. Could the anesthetic freeze the dynamics of MTs so that nerve pulse conduction would become impossible? The presence of an anesthetic should make the axonal interior more negative and induce hyperpolarization.

   Could the presence of the anesthetic stabilize the MTs by minimizing the length of their GDP region? Somehow the growth of MT should be prevented means addition of tubulins and GTPs. This is achieved if the density of tubulin-GTP pairs in axonal water is reduced. The generation of GTP from GDP requires a formation of gravitational HBs from ordinary HBs. The density of ordinary HBs should be reduced.

2. Could the presence of the anesthetic reduce the density of ordinary HBs in the axonal water? HBs are associated with water clusters. How could the presence of anesthetic reduce the rate for the generation of water clusters and therefore HBs in the axonal water?

   In the TGD inspired theory consciousness, the MBs of water clusters can be seen as correlates for mental images of water as a conscious entity [K3] [L26]. The level of consciousness for water would be reduced. It would be water, which is anesthetized! This would freeze the MTs so that also the axonal membrane freezes electrically.

3. Meyer and Overton observed that the potency of anaesthetic agents correlates with their lipid solubility. Anesthetics also seem to affect specific ion channels and receptors. One can argue that if the anesthetic is solvable to lipids, it can also enter inside the axon and somehow reduce the density of HBs assignable to the water molecule clusters accompanied by gravitational MBs. The effective charge of the axonal interior would become more negative and induce a hyperpolarization if the exterior is not affected.

4. How happens when water is anesthetized? A hint comes from the Pollack effect [L3]. The exclusion zones discovered by Pollack are negatively charged regions at the interfaces of hydrophilic surfaces. The TGD based interpretation could be that part of protons become dark protons at gravitational HBs. It is known that anesthetics diminish the amount of EZ water (`https://pubmed.ncbi.nlm.nih.gov/27054588/`).

5. How could anesthetics prevent the formation of EZs and thus of gravitational HBs? A metabolic energy feed is needed in the Pollack effect and is by photons as also the delayed luminescence for MTs demonstrates. How could the feed of photons needed to produce EZs be prevented by anesthetics? Energy is feeded in resonance. Could the presence of anesthetic change the energy needed to transform HB to dark gravitational MB so that the resonance condition would not be satisfied.

4 How multicellular without a nervous system can behave as if it had a nervous system?

In the TGD framework, the quantum models of cell membrane and nerve pulse rely on the notions of magnetic body and dark matter [K1, K6, K7, L14]. The generalization of this view leads to a notion, which could be christened as pre-neural system (PNS). Also the multi-cellulars without CNS would possess PNS.

4.1 Animals without the brain behave as if they had the brain

The motivations for this article came from the Quantum Magazine article (`https://cutt.ly/IDnfovQ`) telling about the findings of Manu Prakash and Mathew Storm Bull. The work of Prakash and Bull is published as 3 articles [**?**]hat can be found in arXiv.org. In the following I summarize the findings as they are described in the popular article.

4.1.1 Findings of Prakash et al

Trichoplax adhaerens is a marine creature, classified as a placozoan, which has the smallest known genome in the animal kingdom. Trichoplax has thousands to few millions of cells and is between prokaryotes and eukaryotes as far complexity is considered.

Trichoplax (`https://cutt.ly/SD6GGW5`) is a very flat organism formed with diameter about 1 mm and thickness about 25 μm. For cell number N in the range $[10^3, 10^6]$ cells and for a cell approximated as a ball with radius r, this gives r in the range $[2.1, 21]$ μm. Despite the lack of neuronal system and muscles, the motion of trichoplax is extremely well-orchestrated and efficient.

The goal of the project of Manu Prakash and his graduate student Matthew Storm Bull was to understand how the neuromuscular system might have evolved and how the early multicellular creatures without a nervous system managed to move, find food and reproduce. Epithelial sheets formed by Trichoplax cells are studied. Trichoplax cells are monociliated that is they have only a single cilium. This simplifies the experimental study and modelling of Trichoplax.

First some basic facts.

1. Motile cilia and flagella are the analogs of muscles and primary (non-motile) ciliar serve the role of sensory organs at the cellular level. Cilia and flagella have similar structures and only their functions differ. Cilia force liquid to move with respect to the cell. Flagella make it possible for the cell to move with respect to liquid (`https://cutt.ly/TDngqh0`).

2. The force needed for the bending of the cilium is produced by the outer and inner dynein arms of the axonemal MT doublets connected to the central pair of microtubules by radial spokes. Airway cilia have components typical for motile cilia.

3. Beating waves as contraction waves of the axoneme induce bending of the cilium. The frequency of the beating wave is the key parameter in the dynamics of the cilium.

   That the beating frequencies are in the EEG range suggests that in some respects neurons and ordinary cells have much more in common than thought. Beating frequency would take care of synchrony and one can ask whether cilia have an analog of EEG.

4.1.2 Popular summary of the experimental findings

I add to the summary my own comments in order to give a hint about TGD based interpretation of the findings.

1. The claim is that behavior of Trichoplax can be described entirely using the language of physics and dynamical systems.

   Comment: To my understanding, a description in this sense means mathematical modelling using formalism of physics and identifying simple basic mechanical functions serving a role analogous to program modules of the software.

The nature of the living systems is very difficult to understand using only recent day physics and it is very difficult to believe that purely mechanistic description could be possible. However, the possibility to construct such a simple model is in itself a strong guideline in attempts to really understand how the motor actions of Trichoplax are possible.

2. Cilia are typically seen in the context of fluids: propelling bacteria or other organisms through water, or moving mucus or cerebrospinal fluids in a body. Therefore the expectation was that the cilia to glide over surfaces, with a thin layer of fluid separating animal and substrate. But when the researchers looked through their microscopes, they saw that the cilia seemed to walk, not swim.

   The claim is that instead of hydrodynamic description, it is possible to have much simpler description in terms mechanics involving notions like friction and adhesion.

   Comment: I understand that these conclusions hold true for the motion along the surface and one can wonder whether the conclusions hold true for swimming.

3. The characterization of the cilia's walking gait was taken as a goal. Only three types of basic motions: slipping, during which the cilia barely grazed the surface; walking, when the cilia adhered to the surface briefly before popping off; and stalling, when the cilia got stuck against the surface.

   Comment: What is really surprising is that the motion consists of such simple basic modules somewhat like a computer program. For instance, in a general Hamiltonian system one expects Hamiltonian chaos. Bohr orbits are what comes into the quantum mind.

Mechanical models for the walking activity were developed by the authors [I14, I12, I13].

1. In the models the walking activity emerged naturally from the interplay between the internal driving forces of the cilia and the effective energy of their adhesion to the surface. The right balance between those two parameters (calculated from experimental measurements of the cilia's orientation, height from the surface and beat frequency in the EEG ranfe in the situation considered) resulted in regular locomotion, with each cilium sticking and then lifting away, like a leg. The wrong balance produced the slipping or stalled phases.

   Comment: My understanding is that the driving force of the cilium serves as an input analogous to external force and chosen so that a model for a particular motion is obtained. The model is therefore not fully deterministic and autonomous. On the other hand, the reduction of hydrodynamical description to mechanical description is highly non-trivial and suggests that some new physics is involved.

2. The walking cilium can be modeled as an excitable system. In an excitable system, the signals spread and get amplified rather than progressively damping out and coming to a stop. A neuron is a classic example of an excitable system. Small voltage perturbations can cause it to fire suddenly, and above some threshold, the new stimulated state propagates to the rest of the system.

   The same phenomenon seems to occur in the cilia. In the experiments and simulations, small perturbations in the height of cilium from the surface, rather than voltage, led to relatively large changes in the activity of nearby cilia. They could suddenly change their orientation, and even switch from a stalled state to a walking one.

   Comment: Excitability, and self-organization in general, is in conflict with the expectations based on second law of thermodynamics. The metabolic energy feed is the way to understand the situation in non-equilibrium thermodynamics.

   This behavior requires an highly non-linear mechanical system at criticality. This does not however explain why so few modes, in fact analogous to Bohr orbits, are possible. A quantum biologist could ask whether quantum criticality is involved. At classical level catastrophic theoretic description in terms of phase transitions is suggestive.

   The similarities with neuronal behaviors inspire the question whether the ciliary system defines some kind of pre-neuronal system preceding the nervous system in evolution and shared by it as the fact that sensory receptors are cells with cilia.

3. It was measured how the mechanical gait of each cilium led to small, local fluctuations in the height h of the tissue. Equations for how this would 'tug' at nearby cells to affect their behavior were deduced, even as the cilia on those cells cycled through movements of their own. A convenient analogy is a network of springs tied together by tiny oscillating motors.

   When the researchers modeled this dance between elasticity and activity, as they called it, they found that the mechanical interactions of cilia pushing against a substrate and cells tugging at each other transmitted information rapidly across the organism.

   Stimulating one region led to waves of synchronized cilia orientation that moved through the tissue. This elasticity and strain in the physics of a walking cilium, now multiplied by millions of them in a sheet, gives rise to coherent motile behavior.

   Comment: Here it is difficult to avoid the question whether the 'tug' as touching of cells (or cilia of different cells) is analogous to synaptic transmission in the neural system.

4. The synchronized orientation patterns could be complex. Sometimes the activity of the system produced vortices, with the cilia oriented around a single point. In other cases, the cilia reoriented in fractions of a second, first pointing one way and then another flocking as a group of starlings or a school of fish might, and resulting in an agility that made it possible for the animal to sometimes change direction on a dime.

   Comment: Courageous quantum biologists might associate with the agility a quantum jump in multi-cellular scale.

5. It was found that the information transmission was selective. After certain stimuli, the energy injected into the system by the cilia just dissipated instead of spreading and changing the organism's behavior. As if the organism would direct its attention to particular parts of the perceptive field and react only to the changes in these parts.

   Comment: Brain is able to direct its attention to particular objects of the perceptive field. Is the ciliary system able to direct its attention?

4.1.3 The model for the cilium and ciliary motor actions

The model starts from the model of nerve pulse and generalizes it to the case of cilium.

Concerning the understanding of the findings about the motor actions of multi-cellulars without a nervous system, this vision raises obvious questions.

1. MB should serve as the "boss" also for the multi-cellulars without a nervous system. The general quantal sensory communication and control mechanism should be the same as for organisms with a nervous system. Frequency modulated dark Josephson radiation should mediate sensory data to MB and dark cyclotron radiation would mediate the control commands from MB as pulse patterns as a response to sensory input.

2. Could the beating wave, which has frequency in EEG range, be analogous to EEG wave, membrane oscillation, and possibly perturbed oscillon/soliton sequence, which defines the ground state of ciliary membrane?

3. Cilia are analogous to axons. Could ciliary membrane act as a Josephson junction communicating sensory data to MB? The MTs of the motile cilia play a role analogous to that of axonal MTs as motor organs of MB. Could one consider analogs of nerve pulses for cilia inducing ciliary motor actions rather than nerve pulse patterns? No nerve pulse is involved. Could the analogs of nerve pulses be pre-nerve pulses analogous to miniature potentials of .4 meV generated in synaptic contacts for instance by acetylcholine containing vesicles (`hhttps://cutt.ly/JD1ONEu`) and induce beating waves inducing ciliary bending? 100-200 hundred miniature potentials are needed to generate a nerve pulse.

4. Here the poorly understood origin of the ATP needed by ciliary motor activities [I18] serves as a guideline. Cilia and flagella cannot have mitochondria as ATP sources inside them and the diffusion of ATP from nearby mitochondria is strongly limited. The proposal discussed in [I18] is that a local generation of ATP using mechanisms, which depend on nutrients could

solve the problem. It is difficult to avoid the feeling that something strange is involved with the ciliary metabolism.

TGD leads to the proposal that the standard metabolic energy quantum of about .5 eV corresponds to the change of gravitational binding energy as a proton of HB is transferred to a dark proton at at the gravitational flux tube around its Bohr orbit in the gravitational field of Earth with gravitational Planck constant $h_{eff} = h_{gr} = GMm/v_0$. Dark electrons would correspond to gravitational binding energy for a valence electron or a pair of valence electrons (Cooper pair) transferred to a gravitational flux tube.

The energy of the single electron metabolic energy quantum would be by a factor $m_e/m_p \sim 2^{-11}$ smaller than the standard metabolic quantum about .25 meV and relate to the standard metabolic energy quantum like cent to dollar. For an electron Cooper pair it would be 2 times larger and about .5 meV. Intriguingly, this energy is rather near to the Coulomb energy change assignable to the miniature potentials .4 meV (`https://cutt.ly/vDRysfU`)! Could the analog of nerve pulse be a propagating miniature potential induced by the dropping of an electron Cooper pair of say Ca^{++} ion from the gravitational Bohr orbit back to Rydberg state with very small binding energy.

5. Cilium is modelled as a 2-D quantum gravitational pendulum with gravitational Planck constant controlled by MB using electronic metabolic energy quanta and the resulting model for the motion is in many respects similar to the model of nerve pulse. In the resting state ciliary penduli oscillate or rotate with constant phase difference so that a wave-like motion results.

6. The analog of nerve pulse transmission can be identified. Temporary fusion of pre- and postsynaptic cells takes place in nerve pulse transmission. The tugs would correspond to the adhesion of their cilia and make possible the transfer of quantum coherence and synchrony between the neighboring cells and in this way generate quantum coherence in multi-cell scale? The adhesion of cilium to the plane in which it moves is also possible.

   Both kinds of adhesions spoil the synchronous oscillation of neighboring penduli. The adhesion followed by de-adhesion changes the relative phase and a further 'tug' is plausible. This leads a domino effect to an analog of nerve pulse conduction. In this process, the U-shaped flux tubes assignable to the cilia of the neighboring cells fuse to form a larger quantum coherent unit. Same would happen in the case of ordinary nerve pulse transmission [L14]. The system is quantum critical in the sense that when the cilia oscillate/rotate with a phase difference below some critical value, no touchings occur and no nerve pulses are generated. Perturbations change the situation.

4.2 Ciliary flocking and emergent instabilities enable collective agility in a non-neuromuscular animal

It is useful to start with a more technical summary of the work of Prakash *et al* provided by the abstract of the article "*Ciliary flocking and emergent instabilities enable collective agility in a non-neuromuscular animal*" [I14] by Mathew Bull, Vivek Prakash, and Manu Prakas as such.

Effective organismal behavior responds appropriately to changes in the surrounding environment. Attaining th

4.3 The analog of the nervous system at the level of multi-ciliary system

The TGD based model for nerve pulse and EEG generalizes in a rather straightforward manner to cilia.

1. Ciliary membranes define pre-neural system. The membranes act as generalized Josephson junctions. The modulations of the oscillation frequency of dark Josephson radiation code for the sensory input to MB. Beating waves have frequencies in EEG range and define the analogs of EEG waves as propagating oscillation patterns of the membrane potential.

2. The first guess is that non-motile cilia serve as sensory receptors mediating sensory input to MB as dark Josephson radiation and motile cilia as motor instruments of MB and analogs

of muscle. Trichoplax has only a single cilium, which acts as a motor organ. Does it also act as a sensory receptor, or does the remaining cell membrane serve in this role?

3. Pre-nerve pulses at the level of animal would correspond to perturbations of the soliton sequences or their oscillatory variants: either one rotating/oscillating pendulum starts to oscillate/rotate. This transition would be induced by the response of MB and cyclotron resonance pulse. Nerve pulse/action potential would be replaced by propagating miniature potential.

4. The ciliary counterparts of action potentials would be analogs of miniature potentials and induced by the electronic metabolic energy quantum. They would represent the response of MB at cilia, propagate to the basal body and proceed as chemical communications to the cell nucleus using second messangers and induce gene expression as a response.

5. The ciliary MBs of cells organize to a larger MB controlling the motion of cell and the MBs of cells in turn organize to even larger MB controlling the collective motion.

6. Synaptic transmission would be replaced with 'tug, that is the touch of neighboring cells, making possible the transfer of the beating waves between the cells. If the touch reduces to the touch of the cilia, the connection with the model of nerve pulse transmission would be even closer. Note however that there is only one flagellum per Trichoplax cell. The orbits of straight ciliar define cones, which correspond to 2-D space-times in 4-D space-time.

   The intersection of these surfaces consist of discrete points in the generic case. If the neighboring cilia rotate with the same frequency and are in the same phase so that the minimal distance between ciliar remains constant, they cannot touch. Above some critical phase difference touching can take place and the touching can occur and the neighboring cilia drop from the phase synchrony.

7. The quantum coherence extended in the fusion of the ciliary MBs generated in the touching of cells or individual cilia. Does also the transfer of local bioharmony take place in the touch. Are the analogs of transmitters involved and affect the bioharmony of the MB of the receiving cell just like nerve transmitters are proposed to do?

4.4 TGD based intepretation of the findings of Prakash *et al*

The findings described in the articles [I14, I12, I13] have made it possible to develop a TGD based picture about the situation.

4.4.1 Homeostasis in the TGD Universe

In biology the balance between sensitivity and stability modelled by Prakash *et al* is known as homeostasis. In biological view, homeostasis is based on a complex many-layered control hierarchies analogous to those used in computation as if a master programmer had written these programs. But can these kinds of control hierarchies really emerge in standard physics?

The proposal of the model of Prakash *et al* is that the 'active-elastic' resonator as a relatively simple mechanical system can at least mimic homeostasis. The model for the epithelial sheet of the animal as a set of oscillators representing cilia coupled by strings. The direction of the cilium defines an effective spin. A resonant coupling of this spin to an external torque represents the control of the motion and parametric resonance allows energy cascades creating collective responses.

In the TGD framework, homeostasis emerges spontaneously via the second law of thermodynamics in reverse time direction.

1. In zero energy ontology (ZEO), biological self-organization and homeostasis involve in an essential manner the possibility of time reversal occurring in "big" (ordinary) state function reduction (BSFR) occuring in long length scales. Time reversal changes repellers to attractors so that homeostasis as an ability of the system to stay near the critical point becomes possible by performing BSFRs.

2. Dissipation of energy is a process in which the coherence scales of excitation decreases. Time reversed periods mean dissipation with a reversed arrow of time and in the model of Prakash *et al* they would correspond to energy cascades proceeding from short to long length scales.

Parametric amplification and a saturating nonlinearity can be seen as the mathematical model for the BSFR inducing time reversal.

1. 'Spikes' mean amplification and in ZEO they could correspond to BSFR changing the arrow of time at the level of MB so that the amplification process would reduce to dissipation with a reversed arrow of time.

2. I have proposed that the interpretation of nerve pulse as a pair of BSFRs temporarily changing the sign of resting potential. An analogous interpretation could make sense now.

4.4.2 Cilium as a quantum gravitational pendulum

The findings of Prakash *et al* makes it possible to consider a concrete TGD inspired model for a single cilium and its dynamics.

1. The observed sub-second time scale for the ciliary reorientations conforms with the interpretation of beating waves are analogs of EEG waves transformed to mechanical waves as longitudinal contraction waves of cilium causing the bending. These waves would be induced by the membrane potential waves of ciliary membrane and in TGD corresponds to waves associated with the Josephson junction defined by the membrane communicating data to the MB of the system characterized by $h_{eff} = h_{gr} = GMm/v_0$.

2. In the first approximation, one can idealize the cilium/flagellum as a rigid linear object of radius $r = .2$ μm, length $l = 100$ μm, and with a density not far from the density of water of 10^3 kg/m^3. The presence of gravitational Planck constant suggests that one can model cilium as a gravitational pendulum with a mass independent oscillation period $T = 2\pi\sqrt{l/g}$, which corresponds to a sub-second time scale $T \simeq .2$ s for $l = 100$ μm.

   The values of l vary in a wide range. For $l = 20$ μm mentioned as an upper bound for the length of flagellum, one has $T \sim .1$ corresponding to 10 Hz EEG resonance frequency. The range $l = 2 - 4$ μm was mentioned in [I3] as a lower bound for the length of beating cilium, corresponds to 25-36 Hz frequency range. In the same source, 10-12 μm was reported as normal cilium length: it corresponds to pendulum frequency 15.8 Hz. Furthermore, the beating frequency was reported to depend only weakly on l so that the beating frequency and pendulum frequency cannot be identified.

   The estimates for the period of the cilium as gravitational pendulum correspond to EEG frequencies as also in the frequency range of beating waves. For $h_{eff} = \hbar_{gr} = GMm/v_0$ and m equal to proton mass, the corresponding transition energies are in the eV scale of biophotons for protons. What puts the bells ringing is that for electrons the energy scale is the same as that of the electronic metabolic energy quantum.

3. As a 2-D gravitational pendulum cilium can also rotate. Angular momentum is quantized as units $h_{eff} = h_{gr}$. Electronic metabolic energy quanta can induce transitions between the harmonic oscillator states of the cilium. The transitions between the states of the quantum gravitational pendulum changing angular momentum would serve as the quantum counterpart for the torque in the models of Prakash *et al*. They would represent the quantum control by MB by using the transformation of gravitationally dark electrons to ordinary electrons.

4.4.3 Correlation between the height of the tissue and membrane potential of cilium

The height h of the tissue is interpreted as a parameter analogous to membrane potential.

1. TGD suggests that the membrane potential of cilium is proportional to the h. The critical height h_{cr} would correspond to a critical value V_{cr} of the ciliary membrane potential for the generation of miniature potential reducing V_{cr}.

2. Cilium as a gravitational pendulum is free when its distance from the surface is larger than the pendulum length l so that $h_{cr} = l$ is a natural identification. When the adhesion occurs MB induces a burst of miniature potentials $\Delta V = .5$ meV feeding electronic metabolic energy quanta to the cilium to achieve de-adhesion.

4.4.4 What happens in the adhesion and de-adhesion?

The key step of the process is the adhesion of cilia to the substrate and its reversal. The probability for the adhesion depends on the tissue height h and obviously vanishes for $h > l$, l the length of cilium. For very small h the cilium sticks on the surface. Part of the cilium would stick to the surface horizontally. Effective adhesion energy is assumed to be in a crucial role. The control action of the cell (animal) is modelled as an external torque on cilium.

Adhesion can also mean that two neighboring cilia moving in opposite direction stick together.

1. In the TGD framework, the de-adhesion could be induced by a transformation of a suitable number of electronic metabolic energy quanta about $E_c = .25$ meV associated with single electron (cilia do not have mitochondria) to the kinetic energy of the cilium as a gravitational pendulum.

   One can estimate the velocity v if the de-adhesion induced by a receival of single metabolic energy quantum E_c from $mv^2/2 = E_c$. This gives $v \simeq 60$ μ m/s. The estimate looks rather reasonable. For the standard metabolic energy quantum .5 eV, one would be $v \simeq 2.7$ mm/s.

2. If momentum is conserved, the change of the horizontal momentum component for the cilia as a pendulum is compensated by the recoil momentum of the entire cell. This gives an estimate for the change ΔV of the velocity of the cell as $\Delta V \sim (m_c/M) \times v$.

4.4.5 Adhesion energy and de-adhesion as precedessor of nerve pulse generation

What the notion of effective adhesion energy could mean in the TGD Universe (note that adhesion energy as a term is misleading since it actually corresponds to adhesion energy per surface area).

1. A very naive order of magnitude estimate used in the modelling of wetting of a surface by water approximates adhesion energy density with the surface tension σ_W for water: $\sigma_w \simeq 7210^{-3} kg/s^2$. This corresponds to an energy density per unit area $\epsilon = .5 \times 10^{-11}$ eV/(μ m)^2. For the cilium with radius $r = .2$ μ m attached vertically this would give $W = sigma_W \pi r^2 \simeq .7 \times 10^{-12}$ eV. This is extremely small energy and looks unrealistic.

2. For instance, if chemical or other kinds of bonds are formed with the surface, the adhesion energy can be even in the eV range. TGD suggests the formation of flux tube bonds between cilia and surface is what comes into mind and the adhesion energy would correspond to the reduction of energy when the bond is formed and shortens by the reduction of h_{eff} as in the basic step of bio-catalysis.

3. The thermal stability of adhesion would suggest that the adhesion energy is of the order of thermal energy, which is of the order .05 eV, which is about 10 percent of the standard metabolic energy quantum. If this is the case, the size of .5 meV for the metabolic energy quantum of electron Cooper pairs implies that at least 100 dark gravitational electrons must transform to ordinary ones to liberate the cilium, which has stuck vertically. Recall that cilia can also stick to each other and the same estimate holds also now as a lower bound coming from the thermal stability of adhesion.

4. Intriguingly, the number of miniature potentials generated by acetylcholine vesicles needed to generate action potential is 100-200 (`hhttps://cutt.ly/JD1ONEu`)! This suggests that the de-adhesion process is a precedessor for the generation of nerve pulse in the postsynaptic neuron. This conforms with the view that the ciliary membrane is a precedessor of axon.

5. Nerve pulse transmission connects the pre- and postsynaptic flux tubes to longer flux tubes and generates larger quantum coherent units. 100-200 miniature potentials generate an action potential after the connection has formed. What could be the counterpart of this at the level of cilia?

Intriguingly, the de-adhesion from the surface requires at least 100 miniature potentials in the model of cilium as a gravitational pendulum. Also the cilia of the neighboring cells can stick together if they move in opposite directions. De-adhesion would require roughly the same energy. Both mechanisms would generate the analog of nerve pulse.

Could the preneural system have transformed to a neural system by the evolution of single flagellum to axon? Could primary cilia have evolved to dendrites? Did flagella having even rather long lengths start to form permanent almost-contacts with the primary cilia of the neighboring cell or even more distant cells, which then developed to synaptic contacts. This would have required the evolution of cilia with radius below .5 μ to axon with radius about 2.5 μm, and containing axonal MTs instead of axonemal MTs. ATP based metabolism in the interior would have emerged besides electron based metabolism, and besides miniature potentials also action potentials and critical membrane potential would have emerged.

4.4.6 Do 'spikes' correspond to real spikes?

Spikes induced by a driving of an 'active-elastic' resonator define a key notion in the models of Prakash *et al*. The intuitive picture of the resonator is as a collection of cilia as motors connected by strings. The 'spikes' would be analogs of nerve pulses. 'Spikes' correspond to tugs inducing flocking and in neuroscience induce formation of larger coherent units of neurons.

In the TGD based model for nerve pulse, spike corresponds to a perturbation coming from MB and transforming the motion of a single pendulum from rotation to oscillation or vice versa. Same should be true now if the cilium is the precedessor of the axon.

1. The active-elastic resonator could correspond to cilia as quantum gravitational penduli and the temporary formation of flux tube connections between the MBs of the penduli could be a counterpart for the formation of strings.

2. A direct touch of cells is not necessary for a 'tug'. The touching of neighboring cilia might be enough and could be regarded as one particular case of adhesion and would be analogous to touch of pre- and postsynaptic cells mediated by the neurotransmitter vesicle. Since the distances between cells are measured in micrometers and if the ciliar lengths are about 100 μ, this is possible.

   In the TGD framework, one can consider the option that cilia do not even touch. Since quantum coherence is at the level of MBs, and what is needed in the TGD framework, is a reconnection of the U-shaped flux tubes associated with the cells: this is assumed to take place also in the synaptic contact in which neurons fused temporarily.

3. The probability for the reconnection of flux tubes (for the touching of cilia) increases as the cells approach each other and could lead to a fusion of several cellular MBs to a larger MB inducing a flock behavior controlled by the larger MB. This would take place when two neighboring ciliary gravitational penduli are in opposite phase with large enough amplitude so that they approach each other.

4. The propagation of nerve pulse would be a domino effect in which the adhesion of neighboring cells or adhesion of cell to surface followed by de-adhesion, which spoils synchronous motion locally and inducies new adhesion. A multiple collision generating quantum coherent at the flux tube level would be in question.

5. In the collective mode the metabolic quanta E_c from cells would arrive in synchrony (but with time lapse to give rise to a wave) so that the cells would walk in synchrony. The rotation of the cilia as gravitational penduli with a constant phase difference gives rise to a wave. In this macroscopic gravitational quantum state Trichoplax would walk. Walking involves gravitation in an essential manner so that the appearance of quantum gravitation is not surprising.

4.4.7 The generation of propagating waves

The model for the generation of propagating waves is very much analogous to the model of axonal membrane as Josephson junction [K6, K1, K7] [L14, L16]. The oscillating waves for the phase

differences of the Cooper pair wave function over Josephson junction define a dynamics analogous to that to a sequence of gravitational penduli. This model could apply as such at the level of ciliary membrane serving as a pre-axon.

The local motion could correspond to oscillation or rotation and the analog of nerve pulse would mean local transformation of oscillation to rotation or vice versa generating soliton or defect of soliton sequence locally.

Also waves that propagate at the level of the entire animal are involved and can be associated with a system of genuine gravitational penduli forming a planar structure. There would also be a propagating wave at the larger MB induced by the temporary fusion of MBs of cilia.

1. The local oscillation of the cilium takes place with the frequency $f = \sqrt{g/l}/2\pi$ of the gravitational pendulum. For the propagating wave $u = \omega t$ is replaced with $\omega(t - x/V)$. The rotation of the pendulum in a vertical rotation plane does not make sense but there are also modes in which the pendulum rotates in plane and have angular momentum which is large since one has $h_{eff} = h_{gr}$ serves as the unit of angular momentum. These modes would be crucial for the control of the motion.

   The speed V of the wave would be analogous to a conduction velocity of nerve pulse. The first guess for the velocity would be as the velocity $V \sim (m_c/M) \times v$, where v is the horizontal velocity gained by the cilium de-attachment already estimated, and m_c and M are the masses of cilium and cell.

2. If one or more metabolic energy quanta E_c feed energy to a single pendulum, the pendulum ceases to be in phase with its neighbors. If the same takes place for MBs, they might reconnect. Could a phase transition initiated by a seed at the level of MBs generate a larger quantum coherent unit analogous to a moving vortex? Energy cascade would correspond to BSFR with time reversal.

4.4.8 Flocking as a generation of quantum gravitational coherence

What could the formation of collective modes, flocking, mean in the TGD framework?

1. The modes of a single cilium correspond to a sticking to the plane without motion, rotation around a roughly elliptical orbit in plane, and rotation without motion. If a single cilium behaves as a solid body, one has a vortex- like structure rotating like a rigid body. Note however that Trichoplax can be very far from a rigid body: it can even split into two parts.

2. The quantal description of the cilia as a quantum gravitational pendulum combined with the conservation of angular momentum suggests that the angular momentum for the center of mass motion of the Trichoplax and the total angular momentum of the ciliary oscillators sum up to zero. This would explain the nearly circular motions. Linear motion of Trichoplax would correspond to a common vertical rotation plane without rotation.

   In fact, both momentum and angular momentum generation could rely on conservation laws and reduce to exchanges of these conserved quantities between MB and system. This seems to be the only option since metabolic energy quanta with $h_{eff} = h$ cannot create forces and torques in the scale of an organism.

   It deserves to be mentioned that the generation of angular momentum of astrophysical objects such as galaxies is poorly understood in the general relativistic framework and the TGD proposal is that the angular momentum of visible matter is accompanied by opposite angular momentum of dark matter and magnetic bodies of astrophysical objects [L7].

3. This model would realize the fractal aspect of holography: the ciliary motion would correspond to the motion of the entire animal. Second aspect of holography is that 3-D data fix the time evolution in the sense that the orbits are analogous to Bohr orbits. In TGD, this is forced by the realization of the general coordinate invariance, and means that the 3-D surface of $H = M^4 \times CP_2$ is almost uniquely determined by a 3-D surface without any data about its 4-D tangent space. Also this aspect of holography is realized and could explain why such an extremely simple model can describe the motion of Trichoplax.

4. Moving vortex-like defects could correspond to the formation of quantum coherent states in which cilia as gravitational penduli are in the same quantum state with non-vanishing angular momentum and non-trivial center-of-mass motion. There is also an analogy with the decomposition of the rotational motion to vortices in super-fluidity.

4.4.9 How could a living system direct its attention?

Prakash *et al* [I14, I12, I13] also found that Trichoplax can also react in a selective manner to perturbations as if it could direct its attention.

According to the TGD inspired theory of consciousness, a metabolic energy feed to the target of attention serves as a correlate for the directed attention. The target corresponds to a mental image of the MB of the system. Mental images have correlates at the level of the space-time surfaces. Space-time surfaces are minimal surfaces with singularities analogous to soap films with frames [L23]. At the frames the dynamics fail to be completely deterministic so that they naturally serve as space-time correlates of mental images. The non-determinism is also finite.

This mental image 'wakes up' in a BSFR separating it from the environment and the superposition of 4-D soap films is reduced so that a single alternative from a finite number of time evolutions is selected. This explains the mysterious looking discovery that during intensive discussion almost anything can happen in the background and remain unnoticed. Sensory input does not lead to a wake up of mental image. The behaviour of the Trichoplax is completely analogous to the behaviour of higher life forms.

4.5 Possible implications of the notion of pre-CNS

The notion of pre-CNS is very general and it is interesting to consider the most obvious implications.

4.5.1 Can organisms without CNS learn?

In [I10] the question whether learning without the nervous system is impossible is considered. Computers are left out of consideration and this restricts the discussion to organic matter. One can consider several definitions for learning. If the change in behaviour is taken as a signature of learning, one ends up to the conclusion that there are large classes of organisms without nervous systems, which are able to learn: paramecia, bacteria and plants are three large classes of this kind of organisms.

There is evidence that multi-cellulars have evolved from the colonies of mono-cellulars, and it is known that colonies of bacteria learn [I11] (`https://cutt.ly/zDOvhuN`). For instance, E. Choli colonies can anticipate changes in the environment by associating higher temperatures with a lack of oxygen. This is the basic type of learning in neural systems and interpreted in terms of changes of synaptic strengths.

Animals with ciliary systems have pre-CNS in the proposed sense, and could learn by essentially the same mechanisms as neuronal networks. Associative learning involves a strengthening of synaptic contacts increasing the probability for the formation of transmitter vesicles. Now this would mean the increase of the probability for the formation of a 'tug' contact and this would lead to the analogs of sub-neural networks.

The model of genetic code based on bioharmony [L2, L13, L17, L27] leads to the proposal that the basic mechanism of learning emerge already at the level of basic biomolecules DNA, RNA, tRNA, and amino acids (AA). Bioharmonies define different moods and the learning by conditioning involves in an essential manner moods affected by the stimulus already at the molecular level. The basic moods would be realized already at the level of basic biomolecules X=DNA, RNA, tRNA, AAs, or rather, the pairings DX-X where DX is the dark analog of X identified as dark nucleon sequence [L27]. Epigenetic mechanisms could stabilize the bioharmonies as correlates for the moods.

There is experimental evidence for this kind of learning (`https://cutt.ly/6SuLNqk`). When the RNA of an animal, which has learned a conditioned behavior, is scattered on the neurons of the animal that has not learned the behavior, the neurons so the signatures of learned behavior. Somehow the RNA transmits the conditioning based on negative or positive emotions generated by the stimulus. The explanation terms of DRNA-RNA pairing carrying the mood infecting the neurons with the conditioned behavior is discussed in the TGD framework in [L6, L8].

4.5.2 Also plants have senses and motor actions

Also plants have senses (https://cutt.ly/mDOA9Zo) and motor actions (for instance, sun flower orients itself towards Sun) and can learn (https://cutt.ly/sDOPUZo).

Can the proposed general model for pre-CNS explain these findings?

1. Microtubules are essential for cilia and axons. In general, plant cells do not have centriole or flagella: the motile, freely swimming sperm cells of some plants are an exception.

   Plants however have root hair (https://cutt.ly/JDOA7rc) consisting of epidermal cells having lateral tubular extensions resembling cilia. Their radius varies between 17-17 μm and the length varies between 80-1,500 μm so that their scale is roughly 100 times larger than that of cilia. The basic function of root-hair cells is to collect water and nutrients from the soil.

2. The MBs of root-hair cells controlling them must be able to receive sensory input from root-hair cells and control their activities. Essentially the same general model seems to work as in the case of axons and cilia.

   The membranes of root-hair cells could serve as sensory receptors using Josephson radiation to communicate the sensory input to MB. Root hair cells do not contain chloroplasts nor do they perform photosynthesis, which suggests that also now the electronic variant of metabolism is involved. The miniature potentials would appear as analogs of nerve pulses.

   Some parts in the stem of the plant can be surrounded by hairy extensions which consist of a single cell or are multicellular structures. Also these could serve as sensory receptors. Note that the hairy geometry would maximize the sensory area.

3. What about the counterpart of the neuron network? Although plant cells are covered by cell walls composed of cellulose, hemicelluloses and pectin, they are not completely isolated. Plasmodesma (https://cutt.ly/9DOSraf) are gap junction-like connections between neighboring plant cells, which allow the transfer of molecules. Plasmodesma could also act as analogs of permanent synaptic contacts, something which brings in mind a meridian system. Note that plasmodesma also have MTs as components.

4. Plants communicate with each other [I5] (https://cutt.ly/PDOSies), for instance via their roots send signals to each other under the soil by using chemical secretions.

   In the TGD Universe, the communications mediated by dark photon signalling via the layers of MB could make indirect communications possible. Plants form communities (https://cutt.ly/eDOSf0F). One can even ask whether for instance a crop field or wood resembling a ciliary community covering a cell membrane could give rise to a higher level nervous system of some kind.

4.5.3 Talking fungi

After having written this article I learned of a fascinating discovery of Andrew Adamatsky [I2], who has studied sponges and found that they show electrical activity sequences of analogs of action potentials ('spikes').

The abstract of the article gives an overview about the findings.

Fungi exhibit oscillations of extracellular electrical potential recorded via differential electrodes inserted into a

The amplitude of spikes varies in the range .03- 2.1 meV. The analogs of miniature potentials correspond to energy .4 meV. The prediction of the TGD based model for the metabolic energy quantum for electron triplet is .51 meV. The solar gravitational metabolism associated with photosynthesis would correspond to the upper bound of 2.5 meV for the metabolic energy. The natural question is whether this kind of communication is specific to fungi or occurs also in preunoral and neuronal systems in general.

The language hypothesis conforms with the TGD based view that the dark variants of genetic code realized using as codons dark photon triplets analogous to 3-chords defining what I call bioharmony serving as a correlate for emotional state and fundamental level [L17, L27]. Dark 3N-photons as representation of for instance genes, define analogs of music pieces. For the TGD

based view of the emergence of human language see [K21]. Genetic code would have number theoretic and geometric origin and would be universal. It would have several realizations and be realized also in other than biological systems.

Dark 3N-photons are analogous to Bose-Einstein condensate of 3N-photons and correspond to so-called Galois singlets, whose formation would rely on a universal number theoretical mechanism for the formation of bound states. The sequence of dark codons selects the receiver, which must possess the same sequence of dark nucleon triplets to achieve resonance. If the frequency scale is modulated, the reception generates a sequence of 3N-pulses analogous to nerve pulse sequence and in this way transforms information coded to frequency modulation to a pulse sequence.

5 Appendix: Basic facts about cilia and flagella

Intermediate filaments, actins and microtubules (MTs) are basic structures of cytoskeleton. MTs are associated with centrosome, cell membrane protrusions known as cilia, flagella, and axons (`https://cutt.ly/FDnfEVP`). Axonal MTs and part of MTs in the cell interior are dynamical and have a varying length. Actins are protrusions of the plasma membrane protrusions known as microvilli (`https://cutt.ly/HDRaxxf`) are analogous to cilia.

Cilia, flagella, axons, and microvilli are involved with motor activities of some kind. In the case of MTs and actins, contractions and lengthenings define the basic element of dynamics. Actin dynamics relates to the gross motion of the cell. The dynamics of axonal MTs might also relate to the nerve pulse conduction. Axonal MTs are not organized into regular structures like the other MTs.

Motile cilia and flagella are precedessors of muscles and motor system. Primary cilia function as antennas and act as mechanical, chemical, and thermal sensory organs.

5.1 Structure and function of cilia

Cilia start from the basal body. One can distinguish between primary and motile cilia (`https://cutt.ly/IDnfKAB`). Unlike motile cilia, primary cilia do not beat and dynein arms and other structures needed for motion are missing. These cilia act as antennas and sensory receptors. All sensory cells have cilia playing the same role so that cilia could be seen as cellular sensory and motor organs.

1. Cilium is a cylindrical protuberance of the plasma membrane. Its radius is about .1 μ m to be compared with axonal radius radius about .25 mum. The length of cilium varies in the range 1-30 μm.

2. Inside cilium is its cytoskeleton known as axoneme. For motile cilia the MTs of the axoneme have 9+2 structure and for primary cilia they have 9+0 structure. For the basal bodies the structure consists of a ring of 9 MT triplets without central MTs. Vertebrates can also have other types of cilia.

3. The 9 pairs of the ring are partially overlapping, which makes it possible for them to glide with respect to each other: this induces the bending of the motile cilium. The tubulins of these pairs are horizontally connected by nexin bonds to form a ring-like structure. Radial spokes and outer and inner dynein arms force the gliding motion.

   The pairs or rings consist of two kinds of MTs. The MT of type A has 13 tubulin protofilaments and MT of type B has 10 protofilaments. In motile cilia and flagella, structures essential for motility, such as axonemal dyneins, radial spokes, and the nexin dynein regulatory complex (N-DRC), are arranged on DMTs with a 96-nm repeating unit.

4. The members of the central pair are non-overlapping MTs connected by a bridge. The center MTs are involved with the control of the ciliary motion induced by the gliding.

   Stabilization of cilia MTs is by inner lumen proteins. The structure and protein composition of motile cilia and flagella are well conserved among eukaryotes.

5.2 Beating waves

Cilia and flagella have similar structures and only their functions differ. Cilia force liquid to move with respect to the cell. Flagella make it possible for the cell to move with respect to liquid (https://cutt.ly/TDngqhO). The force needed for cilia beating is produced by the outer and inner dynein arms of the axonemal microtubule doublets connected to the central pair of microtubules by radial spokes. Airway cilia have components typical for motile cilia.

1. Motile cilia and flagella beat in a synchronized pattern. This coordination is achieved by metachronal rhythm, in which a wave of simultaneously beating groups of cilia moves from the anterior to the posterior end of the organism. The motions of cilia along the cell surface have different phases so that the motion looks like a wave: mexican wave (https://cutt.ly/iDRUehV) is a good example of this. The waves in the crop field induced by wind serve as a good example.

2. The cilia on the same line perpendicular to the direction of the effective stroke are synchronized and thus have the same phase, and adjacent rows of cilia parallel to the direction of the effective stroke beat with a phase difference.

   Beating corresponds to a contraction wave and here the dynein arms are in an essential role. Orientation, beating frequency, wavelength, amplitude parametrize the motion of cilium.

3. Waves begin from cilia rather than the basal body so that the obvious idea that the cell would initiate the motion, need not be correct. Various wave forms such as plane waves and non-symmetric waves cause the bending.

4. The beating frequency varies in EEG range, which need not be an accident. Some sources report beating frequencies in the range 4-10 Hz. Some sources report 20-60 Hz frequency (https://cutt.ly/uDngfyO).

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