TGD and condensed matter

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Abstract

Condensed matter physics is under rapid evolution, one might even speak of revolution. New exotic states of matter are discovered and their theoretical understanding in the existing theoretical framework is highly challenging. The findings challenge the existing reductionistic framework and it is quite possible that new physics is required. This motivates the question whether the new physics provided by TGD could provide some understanding. The general view about condensed matter in TGD Universe is following.

1. TGD is analogous to hydrodynamics in the sense that field equations at the level of H reduce to conservation laws for isometry charges. The preferred extremal property meaning that space-time surfaces are simultaneous extremals of volume action and Kähler action allows interpretation in terms of induced gauge fields. The generalized Beltrami property implies the existence of an integrable flow serving as a correlate for quantum coherence. Conserved Beltrami flows currents correspond to gradient flows. At the QFT limit this simplicity would be lost.
2. The fields H, M, B and D, P, E needed in the applications of Maxwell's theory could emerge at the fundamental level in the TGD framework and reflect the deviation between Maxwellian and the TGD based view about gauge fields due to CP_2 topology.
3. The understanding of macroscopic quantum phases improves. The role of the magnetic body carrying dark matter is central. The understanding of the role of WCW degrees of freedom improves considerably in the case of Bose-Einstein condensates of bosonic particles such as polaritons. M^8 picture allows us to understand the notion of skyrmion. The formation of Cooper pairs and analogous states with higher energy would correspond to a formation of Galois singlets liberating energy used to increase h_{eff}. What is new is that energy feed makes possible supra-phases and their analogs above the critical temperature. TGD description of Cooper pairs is consistent with fermion number conservation and the notion of Bogoliubov quasiparticles does not seem necessary or relevant in TGD.
4. Fermi surface emerges as a fundamental notion at the level of M^8 but has a counterpart also at the level of H. Galois groups would be crucial for understanding braids, anyons and fractional Quantum Hall effect. Galois confinement suggests a universal mechanism for the formation of bound states. Space-time surface could be seen as a curved quasicrystal associated with the lattice of M^8 defined by algebraic integers in an extension of rationals. Also the TGD analogs of condensed matter Majorana fermions emerge.
5. TGD also provides new insights about topological physics and space-time topology provides a new element of topological physics.

In this article, the basic notions of condensed matter physics are discussed from the TGD point view, some concrete problems of condensed matter are considered, and some tests are proposed.

1 Introduction

The purpose of this article is to give a rough overall view about Topological Geometrodynamics (TGD) and to consider its possible applications in condensed matter physics at the general level. It must be emphasized that TGD is only a vision, not a theory able to provide precise rules for calculating scattering amplitudes. A collective theoretical and experimental effort would be needed to achieve this. The proposal for a model of superconductivity [L39] provides a representative example about what TGD could possibly give for condensed matter physics.

It is perhaps good to explain what TGD is not and what it is or hoped to be. The article [L33] gives an overview of various aspects of TGD and is warmly recommended.

1. "Geometro-" refers to the idea about the geometrization of physics. The geometrization program of Einstein is extended to gauge fields allowing realization in terms of the geometry of surfaces so that Einsteinian space-time as abstract Riemann geometry is replaced with sub-manifold geometry. The basic motivation is the loss of classical conservation laws in General Relativity Theory (GRT)(see **Fig. 1**). Also the interpretation as a generalization of string models by replacing string with 3-D surface is natural.

   Standard model symmetries uniquely fix the choice of 8-D space in which space-time surfaces live to $H = M^4 \times CP_2$ [L1]. Also the notion of twistor is geometrized in terms of surface geometry and the existence of twistor lift fixes the choice of H completely so that TGD is unique [L17, L21](see **Fig. 6**). The geometrization applies even to the quantum theory itself and the space of space-time surfaces - "world of classical worlds" (WCW) - becomes the basic object endowed with Kähler geometry (see **Fig. 7**). General Coordinate Invariance (GCI) for space-time surfaces has dramatic implications. Given 3-surface fixes the space-time surface almost completely as analog of Bohr orbit (preferred extremal).This implies holography and leads to zero energy ontology (ZEO) in which quantum states are superpositions of space-time surfaces.

2. Consider next the attribute "Topological". In condensed matter physical topological physics has become a standard topic. Typically one has fields having values in compact spaces, which are topologically non-trivial. In the TGD framework space-time topology itself is non-trivial as also the topology of $H = M^4 \times CP_2$.

   The space-time as 4-surface $X^4 \subset H$ has a non-trivial topology in all scales and this together with the notion of many-sheeted space-time brings in something completely new. Topologically trivial Einsteinian space-time emerges only at the QFT limit in which all information about topology is lost (see **Fig. 3**).

   Practically any GCI action has the same universal basic extremals: CP_2 type extremals serving basic building bricks of elementary particles, cosmic strings and their thickenings to flux tubes defining a fractal hierarchy of structure extending from CP_2 scale to cosmic scales, and massless extremals (MEs) define space-time correletes for massless particles. World as a set or particles is replaced with a network having particles as nodes and flux tubes as bonds between them serving as correlates of quantum entanglement.

   "Topological" could refer also to p-adic number fields obeying p-adic local topology differing radically from the real topology (see **Fig. 10**).

3. Adelic physics fusing real and various p-adic physics are part of the number theoretic vision, which provides a kind of dual description for the description based on space-time geometry and the geometry of "world of classical" orders. Adelic physics predicts two fractal length scale hierarchies: p-adic length scale hierarchy and the hierarchy of dark length scales labelled by $h_{eff} = nh_0$, where n is the dimension of extension of rational. The interpretation of the latter hierarchy is as phases of ordinary matter behaving like dark matter. Quantum coherence is possible in all scales.

   The concrete realization of the number theoretic vision is based on $M^8 - H$ duality (see **Fig. 8**). The physics in the complexification of M^8 is algebraic - field equations as partial differential equations are replaced with algebraic equations associating to a polynomial with rational coefficients a X^4 mapped to H by $M^8 - H$ duality. The dark matter hierarchy corresponds to a hierarchy of algebraic extensions of rationals inducing that for adeles and has interpretation as an evolutionary hierarchy (see **Fig. 9**).

   $M^8 - H$ duality provides two complementary visions about physics (see **Fig. 2**), and can be seen as a generalization of the q-p duality of wave mechanics, which fails to generalize to quantum field theories (QFTs).

4. In Zero energy ontology (ZEO), the superpositions of space-time surfaces inside causal diamond (CD) having their ends at the opposite light-like boundaries of CD, define quantum states. CDs form a scale hierarchy (see **Fig. 12** and **Fig. 13**).

   Quantum jumps occur between these and the basic problem of standard quantum measurement theory disappears. Ordinary state function reductions (SFRs) correspond to "big" SFRs (BSFRs) in which the arrow of time changes (see **Fig. 14**). This has profound thermodynamic implications and the question about the scale in which the transition from classical to quantum takes place becomes obsolete. BSFRs can occur in all scales but from the point of view of an observer with an opposite arrow of time they look like smooth time evolutions.

   In "small" SFRs (SSFRs) as counterparts of "weak measurements" the arrow of time does not change and the passive boundary of CD and states at it remain unchanged (Zeno effect).

This work led to considerable progress in several aspects of TGD.

1. The mutual entanglement of fermions (bosons) as elementary particles is always maximal so that only fermionic and bosonic degrees can entangle in QFTs. The replacement of point-like particles with 3-surfaces forces us to reconsider the notion of identical particles from the category theoretical point of view. The number theoretic definition of particle identity seems to be the most natural and implies that the new degrees of freedom make possible geometric entanglement.

   Also the notion particle generalizes: also many-particle states can be regarded as particles with the constraint that the operators creating and annihilating them satisfy commutation/anticommutation relations. This leads to a close analogy with the notion of infinite prime.

2. The understanding of the details of the M^8-H duality forces us to modify the earlier view. The notion of causal diamond (CD) central to zero energy ontology (ZEO) emerges as a prediction at the level of H. The pre-image of CD at the level of M^8 is a region bounded by two mass shells rather than CD. M^8-H duality maps the points of cognitive representations as momenta of quarks with fixed mass in M^8 to either boundary of CD in H.

3. Galois confinement at the level of M^8 is understood at the level of momentum space and is found to be necessary. Galois confinement implies that quark momenta in suitable units are algebraic integers but integers for Galois singlet just as in ordinary quantization for a particle in a box replaced by CD. Galois confinement could provide a universal mechanism for the formation of all bound states.

4. There is considerable progress in the understanding of the quantum measurement theory based on ZEO. From the point of view of cognition BSFRs would be like heureka moments and the sequence of SSFRs would correspond to an analysis having as a correlate the decay of 3-surface to smaller 3-surfaces.

The improved vision allows us to develop the TGD interpretation for various condensed matter notions.

1. TGD is analogous to hydrodynamics in the sense that field equations at the level of H reduce to conservation laws for isometry charges. The preferred extremal property meaning that space-time surfaces are simultaneous extremals of volume action and Kähler action allows interpretation in terms of induced gauge fields. The generalized Beltrami property implies the existence of an integrable flow serving as a correlate for quantum coherence. Conserved Beltrami flows currents correspond to gradient flows. At the QFT limit this simplicity would be lost.

2. The fields H, M, B and D, P, E needed in the applications of Maxwell's theory could emerge at the fundamental level in the TGD framework and reflect the deviation between Maxwellian and the TGD based view about gauge fields due to CP_2 topology.

3. The understanding of macroscopic quantum phases improves. The role of the magnetic body carrying dark matter is central. The understanding of the role of WCW degrees of freedom improves considerably in the case of Bose-Einstein condensates of bosonic particles such as polaritons. M^8 picture allows us to understand the notion of skyrmion. The formation of Cooper pairs and analogous states with higher energy would correspond to a formation of Galois singlets liberating energy used to increase h_{eff}. What is new is that energy feed makes possible supra-phases and their analogs above the critical temperature.

4. Fermi surface emerges as a fundamental notion at the level of M^8 but has a counterpart also at the level of H. Galois groups would be crucial for understanding braids, anyons and fractional Quantum Hall effect. Space-time surface could be seen as a curved quasicrystal associated with the lattice of M^8 defined by algebraic integers in an extension of rationals. Also the TGD analogs of condensed matter Majorana fermions emerge.

In section 1 this picture is discussed in more detail. In section 2 some concepts of condensed matter physics are discussed from the TGD view. In section 3 some concrete questions about condensed matter are discussed Hydrodynamical turbulence represents one of the unsolved problems of physics and therefore as an excellent test bench for the TGD based vision and is discussed in the 4^{th} section. The last section lists some tests for the TGD based vision. The approach is rather general: this is the only possible option since I am not a condensed matter specialist.

2 Some notions of condensed matter physics from the TGD point of view

Before continuing I must emphasize that I am not a condensed matter physicist and have no practical experience about experimental physics. Therefore I cannot propose any experimental protocols. I dare to hope that the new vision about space-time and quantum theory could inspire people who are doing real condensed matter physics.

2.1 The notion of Brillouin zone from the TGD viewpoint

In condensed matter physics the notions of lattice, reciprocal lattice, unit cell and Brillouin zone at its counterpart in reciprocal lattices are central notions.

The reciprocal lattice in momentum space is the dual of the lattice in 3-space. This follows automatically from the periodicity of properties of wave functions in the lattice : they force wave vectors to be in the reciprocal lattice. The diffraction amplitude has peaks at the photon momenta in the reciprocal lattice.

M^8-H duality can be seen as the counterpart of position-momentum duality. Therefore it is interesting to look at these notions from the point of view of M^8_H duality. Recall that 4-surfaces in $H=M^4\times CP_2$ is identified as space-time whereas the 4-surface in $M^8=M^4\times E^4$ is analogous to momentum space with slicing induced by the mass shells (hyperboloids) of M^4. In H the corresponding slicing is by CDs inside CDs with size given by the Compton length associated with mass m.

1. At the level of H, periodic minimal surfaces would nicely produce lattice-like structures and the momenta associated with the peaks of Fourier transforms would belong to the reciprocal lattice. I have considered the construction of also more general structures in [L55].

2. At the level of M^8, the allowed momenta as points of $X^4\subset M^8$ belong to cognitive representations: the momentum components are algebraic integers in the extension defined by the polynomial defined the 4-surface in M^8. This guarantees the theoretical universality of the adelic physics [L15, L16]) so that the points make sense also as points of the p-adic variants of space-time surface defining geometric correlates of cognition.

   Lattice-like structures are naturally associated with the lattice of algebraic integers and one obtains a hierarchy of lattices. The lattices can be seen as products of ordinary lattices in E^3 and lattices in the extension of rationals having dimension n: this feature is completely new.

2.1.1 Construction of bound states

Number theoretic vision suggests a universal way to construct bound states as Galois confined states. This would mean that many quark states in M^8 consisting of points of cognitive representation carrying quark are Galois singlets. In the case of momentum degrees of freedom this would mean that the total momentum is (rational) integer.

The physical motivation for Galois confinement is that periodic boundary conditions require integer value 4-momenta which are rational integers using a suitable momentum unit determined by the size scale of CD (Compton length $\hbar_{eff}/m$ for some particle would be in question for $\hbar_{eff}=\hbar_{gr}=GMm/v_0$ the gravitational Compton length $\Lambda_{gr}=GM/v_0=r_s(M)/2v_0$ would not depend at all on mass of the particle.

1. The condition that the total 4-momentum is integer-valued poses a strong condition on the bound states.

2. Second condition is that the inner products of the momenta (algebraic integers which can have an imaginary part) defining number theoretical metric are real valued. This poses strong quantization conditions, and one obtains also lattice structures in the lattice defined by the unit vectors of extension and by 3-space. These lattice structures are sublattices of lattice E^3, whose points are n-D number theoretical lattices defined by the unit vectors of the extension of rationals.

3. The fundamental entities are quarks and the construction gives a hierarchy of increasingly complex bound states of them. One obtains also atoms and their lattices. Quasi-crystals are obtained as cut and project construction and it is feasible that number theoretical lattices makes them possible also now.

4. The lattices in M^8 involving particles with the same mass are actually lattices in 3-D hyperbolic space and called tessellations. In good approximation they are lattices in E^3 since H^3 can be approximated by E^3 below length scale given by h_{eff}/m which is Λ_{gr} for $\hbar_{gr}$ (.9 cm for Earth and of the order of radius of Earth for Sun).

   The structure of tessellations is extremely rich and perhaps the simplest tessellations known as icosa-tetrahedral tessellations involve all basic Platonic solids and are proposed to give rise to universal realization of genetic code having chemical realization only as a special case and having besides DNA also higher dimensional realizations [L44].

   M^8 picture allows also universal 6-D brane-like solutions with a topology of 6-sphere, whose projection to CD is its intersection with 3-D hyperplane E^3 of constant energy. This plane would allow many quarks states with an ordinary lattice structure. There both hyperbolic tessellations and Euclidian lattices would be allowed.

5. Even the lattice formed by atoms would be a bound state of this kind. The reciprocal lattice in M^8 has an interpretation in terms of cognitive representation in M^8 mapped to H by M^8-H duality defined by particle momenta, which are basically bound states of quarks (also leptons).

2.1.2 M^8-H duality and the relation between lattices and reciprocal lattices

M^8 and H descriptions are related by M^8-H duality as an analog for momentum-position duality. Uncertainty Principle (UP) must be respected but what does this really require is not quite clear. The map of $X^4 \subset M^8$ to $X^4 \subset H$ is certainly involved. This would be the M^8-H duality for space-time surfaces. This description is not enough: M^8-H duality is required also at the level of "world of classical worlds" (WCW).

1. M^8-H duality at the level of 4-surfaces

Consider first the M^8-H duality at space-time level.

1. Uncertainty Principle (UP) is the basic constraint on M^8-H duality and fixes the form of M^8-H duality at the space-time level.

   One takes the momentum projection p in M^4 - an algebraic integer for cognitive representations and quarks are at these points, not all - and maps it to a point of $M^4 \subset M^4 \times CP_2$ that is to a point of $X^4 \subset H$. One assigns to p a geodesic line in the direction of momentum beginning at the common center of all CDs. In this way the slicing by mass shells of $M^4 \subset M^8$ is mapped to a slicing by CDs inside CDs (Russian doll-like structure).

2. p is mapped to the intersection of this geodesic line with the boundary of CD. One obtains the analog of the pattern produced by diffraction from the lattice. In particular, the intersections of the geodesics with the $t=T$ plane above the center point of CD form a reciprocal lattice, whose projection to the 2-D surface of a large 2-sphere corresponds to the standard diffraction pattern. One would be happy if one would obtain a lattice, rather than its reciprocal.

As if there were a lattice around the center of the ball producing the diffraction pattern as a projection of the reciprocal lattice to the heavenly sphere. Intuition would suggest that this must be the case but one must be very cautious.

3. The momenta of quarks (or atoms) are therefore mapped to the light-cone boundaries of CD and basically define boundary values for the induced quark fields for quarks composing both proton, nuclei, and even electrons. These fields would be localized at these points at the boundary of CD and disperse in the interior. Induced spinor fields are second quantized H-spinor fields restricted to space-time surface and obeying modified Dirac equation for induced geometry and determined by variational principle.

   One can assign to the points at the boundary of CD corresponding to the image of the reciprocal lattice localized states of atoms of the lattice (many-quark states). At quark level this corresponds to a superposition of spinor harmonics of H localized to the point of the boundary (this corresponds to so-called light-cone quantization). This would dictate the time evolution of the induced spinor field inside the space-time surface and it would reflect the data coding for the reciprocal lattice.

4. Does this mean the emergence of lattice (as desired) or of reciprocal lattice in the interior? Since the lattice points by definition would correspond to peaks of plane waves generated by the reciprocal lattice at the boundary of CD would expect that the peak positions define the lattice.

One can also wonder whether one could one define $M^8 - H$ duality so that it would take momentum lattice in M^8 to its dual in H? The notion of dual lattice makes sense for the lattice defined by the extension. If one defines the cognitive representation in M^8 by selecting a tessellation at the mass shell of M^8 (this might follow the conditions for bound states), one could map the momenta of tessellations to their duals and would obtain the desired result in H. It is however not clear whether the map of tessellation to its dual (if it exists) can be completed to a continuous map of H^3 to itself.

2. $M^8 - H$ duality at the level of WCW

It seems that the proposed description need not be enough to realize UP at the level of H and the "world of classical worlds" (WCW) . The objection is that localized states in M^8 correspond to delocalized states at the level of H.

The above description maps quarks at points of $X^4 \subset M^8$ to states of induced spinor field localized at the 3-D boundaries of CD but necessarily delocalized into the interior of the space-time surface $X^4 \subset H$. This is analogous to a dispersion of a wave packet. One would obtain a wave picture in the interior and the lattice should emerge.

1. The basic observation leading to TGD is that in the TGD framework a particle as a point is replaced with a particle as a 3-surface, which by holography corresponds to 4-surface.

   Momentum eigenstate corresponds to a plane wave. Now planewave could correspond to a delocalized state of 3-surface associated with a particle in M^4 and by holography that of 4-surface.

2. A generalized plane wave would be a quantum superposition of shifted space-time surfaces with a phase factor determined by 4-momentum. This suggests that $M^8 - H$ duality should map the point of M^8 containing an object with momentum p to a generalized plane wave and this is assumed.

   This would also define WCW description. Recent physics relies on the assumption about single background space-time: WCW is effectively replaced with M^4 since 3-surface is replaced with point and CP_2 is forgotten so that one must introduce gauge fields and metric as primary field variables.

3. For cognitive representations, momenta are given by algebraic integers. Lattice plane waves can be idealized as waves in a discrete lattice. This would suggest that the plane wave is replaced by a discretized plane wave corresponding to the points of H at which the plane wave has the same value. One can say that one counts only the wave crests and thus only the information about wavelength and frequency.

4. For reciprocal momenta, one obtains a wave function in H for the shifted images of the 3-surface/4-surface labelled by a vector of the reciprocal lattice in H and this wave function can be regarded as a wave function with the periodicities of lattice.

The WCW picture is necessary if one wants to take into account WCW degrees of freedom. In the approximate description of phenomena involving only elementary particles constructible from quarks, WCW is not absolutely necessary.

2.1.3 Galois confinement and lattice like structures

It is interesting to look more explicitly at the conditions for the Galois confinement.

Single quark states have momenta, which are algebraic integers generated by so called integral basis (https://cutt.ly/SRuZySX) analogous to unit vectors of momentum lattice but for single component of momentum as vector in extension. There is a theorem stating that one can form the basis as powers of a single root. It is also known that irreducible monic polynomials have algebraic integers as roots.

1. In its minimal form Galois confinement states that only momenta, which are rational integers, are allowed by Galois confinement. Note that for irreducible polynomials with rational coefficients one does not obtain any rational roots. If one assumes that single particle states can have an arbitrary algebraic integer as a momentum, one also obtains rational integers for momentum values. These states are not at mass - or energy shell associated with the single particle momenta.

2. A stronger condition would be that also the inner products of the momenta involved are real so that one has $Re(p_i) \cdot Im(p_j) = 0$. For $i = j$ this gives a condition possible only for the real roots for the real polynomials defining the space-time surface.

To see that real roots are some facts about the realization of the co-associativity condition [L29] are necessary.

1. The expectation is that the vanishing condition for the real part (in a quaternionic sense) of the octonionic polynomial gives a co-associative surface. By the Lorentz symmetry one actually obtains as a solution a 6-D complex mass shell $m_c^2 \equiv m_{Re}^2 - m_{Im}^2 + 2iRe(p) \cdot Im(p) = r_1$, where the real and imaginary masses are defined are $m_{Re}^2 = Re(p)^2$ and $m_{Im}^2 = Im(p)^2$ and r_1 is some root for the odd part of the polynomial P assumed to determining the 4-surface.

2. This surface can be co-associative but would also be co-commutative. Maximally co-associative surface requires quaternionic normal space and the proposal is that the 6-surface having a structure of S^2 bundle defines as its base space quaternionic 4-surface. This space would correspond to a gauge choice selecting a point of S^2 at every point of M^4. To a given polynomial one could assign an entire family of 4-surfaces mapped to different space-time surfaces in H. A possible interpretation of gauge group would be as quaternionic automorphisms acting on the 2-sphere.

Concerning Galois confinement, the basic result is that for complex roots r_1 the conditions $Re(p_i) \cdot Im(p_i) = 0$ cannot be satisfied unless one requires that r_1 is real. Therefore the stronger option makes sense for real roots only.

Despite this one can also consider the strong option for real roots. There are two cases to consider. The first case corresponds to complex 4-surfaces for which complex mass squared is equal to a root of the odd part of the polynomial determining the space-time surface. The real part of these surfaces in the sense that the imaginary part of mass squared vanishes is 4-D.

These conditions lead to a spectrum of 4-momenta and masses with each mass involving a subset of momenta. One can form Galois singlets also from states with different masses.

1. One can assign to each algebraic integer n_A a Galois invariant defined as the determinant $det(N(n_A))$ of the matrix $N(n_A)$ of the linear transformation defined by a multiplication of the units of algebraic integers by n_A. The algebraic integers n_A with the same value of $det(N(n_A))$ can belong to the orbit of Galois group. Physical intuition suggests that the values of mass squared (energy) are the same for these integers in the case of H^3.

2. One expects that the group $SL(2, Z_A)$, where Z_A denotes algebraic integers associated with the polynomial defining the space-time surface produces new solutions from a given solution. This would be a discrete version of Lorentz invariance. Tessellations of H^3 are highly suggestive as bound states.

3. Since Galois group is finite, the only possibility is that Galois groups corresponds to a subgroup of rotations permuting algebraic integers with the same time-component of 4-momentum. Therefore the discrete subgroups of $SO(3)$ associated with the inclusions of hyper-finite factors of type II_1 would emerge.

The situation for the surfaces $E = E_n$, E_n the root of the polynomial P defined the 4-surface situation is different.

1. Single particle states correspond to a discrete set of in general complex mass values extending from E_n to 0. The number of momenta with given m is finite and one obtains a slicing of the space of 3-momenta by spheres $S^2(m)$ with constant mass having the allowed points of $S^2(m)$ at the orbits of Galois group. Also now single particle states are impossible but one obtains many-particle states and also lattice like structures are expected. A given mass m can correspond to several energies $E_n(m)$ giving this value of mass.

2. Also now it is possible to construct Galois singlets as many-particle states and these have rational integer valued momenta. In condensed matter, one has energy bands such that the energy inside the band depends on the momentum k. Could one think that the values of energy form bands decomposing to discrete energy levels?

Two further remarks are in order.

1. Besides the simplest realization also a higher level realization is possible: Galois singlets are not realized in the space of momenta but in the space of wavefunctions of momenta. States of an electron in an atom serve as an analogy. Origin is invariant under the rotation group and electron at origin would be the classical analog of a rotationally invariant state. In quantum theory, this state is replaced with an s-wave invariant under rotations although its argument is not.

   In the recent situation, one would have a wave function in the space of algebraic integers representing momenta, which are not Galois invariants but if one has Galois singlet, the average momentum as Galois invariant is ordinary integer. Also single-quark states could be Galois invariant in this sense.

2. The proposal inspired by TGD inspired quantum biology is that the polynomials defining 4-surface in M^8 vanish at origin: $P(0) = 0$. One can form increasingly complex 4-surfaces in M^8 by forming composite polynomials $P_n \circ P_{n-1} \circ ... \circ P_1$ and these polynomials have roots of P_1....and P_{n-1} as their roots. These roots are like conserved genes: also the momentum spectra of Galois singlets are analogous to conserved genes. This construction applies to Galois singlets in both classical and quantal sense.

   At the highest level one can construct states as singlets under the entire Galois group. One can use non-singlets of previous level as building bricks of these singlets.

2.1.4 About the analogs of Fermi torus and Fermi surface in H^3

Fermi torus (cube with opposite faces identified) emerges as a coset space of E^3/T^3, which defines a lattice in the group E^3. Here T^3 is a discrete translation group T^3 corresponding to periodic boundary conditions in a lattice.

In a realistic situation, Fermi torus is replaced with a much more complex object having Fermi surface as boundary with non-trivial topology. Could one find an elegant description of the situation?

1. Hyperbolic manifolds as analogies for Fermi torus?

The hyperbolic manifold assignable to a tessellation of H^3 defines a natural relativistic generalization of Fermi torus and Fermi surface as its boundary. To understand why this is the case, consider first the notion of cognitive representation.

1. Momenta for the cognitive representations [L67] define a unique discretization of 4-surface in M^4 and, by $M^8 - H$ duality, for the space-time surfaces in H and are realized at mass shells $H^3 \subset M^4 \subset M^8$ defined as roots of polynomials P. Momentum components are assumed to be algebraic integers in the extension of rationals defined by P and are in general complex.

   If the Minkowskian norm instead of its continuation to a Hermitian norm is used, the mass squared is in general complex. One could also use Hermitian inner product but Minkowskian complex bilinear form is the only number-theoretically acceptable possibility. Tachyonicity would mean in this case that the real part of mass squared, invariant under $SO(1,3)$ and even its complexification $SO_c(1,3)$, is negative.

2. The active points of the cognitive representation contain fermion. Complexification of H^3 occurs if one allows algebraic integers. Galois confinement [L67, L63] states that physical states correspond to points of H^3 with integer valued momentum components in the scale defined by CD.

   Cognitive representations are in general finite inside regions of 4-surface of M^8 but at H^3 they explode and involve all algebraic numbers consistent with H^3 and belonging to the extension of rationals defined by P. If the components of momenta are algebraic integers, Galois confinement allows only states with momenta with integer components favored by periodic boundary conditions.

Could hyperbolic manifolds as coset spaces $SO(1,3)/\Gamma$, where Γ is an infinite discrete subgroup $SO(1,3)$, which acts completely discontinuously from left or right, replace the Fermi torus? Discrete translations in E^3 would thus be replaced with an infinite discrete subgroup Γ. For a given P, the matrix coefficients for the elements of the matrix belonging to Γ would belong to an extension of rationals defined by P.

1. The division of $SO(1,3)$ by a discrete subgroup Γ gives rise to a hyperbolic manifold with a finite volume. Hyperbolic space is an infinite covering of the hyperbolic manifold as a fundamental region of tessellation. There is an infinite number of the counterparts of Fermi torus [L44]. The invariance respect to Γ would define the counterpart for the periodic boundary conditions.

   Note that one can start from $SO(1,3)/\Gamma$ and divide by $SO(3)$ since Γ and $SO(3)$ act from right and left and therefore commute so that hyperbolic manifold is $SO(3) \setminus SO(1,3)/\Gamma$.

2. There is a deep connection between the topology and geometry of the Fermi manifold as a hyperbolic manifold. Hyperbolic volume is a topological invariant, which would become a basic concept of relativistic topological physics (`https://cutt.ly/RVsdNl3`).

   The hyperbolic volume of the knot complement serves as a knot invariant for knots in S^3. Could this have physical interpretation in the TGD framework, where knots and links, assignable to flux tubes and strings at the level of H, are central. Could one regard the effective hyperbolic manifold in H^3 as a representation of a knot complement in S^3?

   Could these fundamental regions be physically preferred 3-surfaces at H^3 determining the holography and $M^8 - H$ duality in terms of associativity [L29, L30]. Boundary conditions at the boundary of the unit cell of the tessellation should give rise to effective identifications just as in the case of Fermi torus obtained from the cube in this way.

2. De Sitter manifolds as tachyonic analogs of Fermi torus do not exist

Can one define the analogy of Fermi torus for the real 4-momenta having negative, tachyonic mass squared? Mass shells with negative mass squared correspond to De-Sitter space $SO(1,3)/SO(1,2)$ having a Minkowskian signature. It does not have analogies of the tessellations of H^3 defined by discrete subgroups of $SO(1,3)$.

The reason is that there are no closed de-Sitter manifolds of finite size since no infinite group of isometries acts discontinuously on de Sitter space: therefore these is no group replacing the Γ in H^3/Γ. (`https://cutt.ly/XVsdLwY`).

3. Do complexified hyperbolic manifolds as analogs of Fermi torus exist?

The momenta for virtual fermions defined by the roots defining mass squared values can also be complex. Tachyon property and complexity of mass squared values are not of course not the same thing.

1. Complexification of H^3 would be involved and it is not clear what this could mean. For instance, does the notion of complexified hyperbolic manifold with complex mass squared make sense.

2. $SO(1,3)$ and its infinite discrete groups Γ act in the complexification. Do they also act discontinuously? p^2 remains invariant if $SO(1,3)$ acts in the same way on the real and imaginary parts of the momentum leaves invariant both imaginary and complex mass squared as well as the inner product between the real and imaginary parts of the momenta. So that the orbit is 5-dimensional. Same is true for the infinite discrete subgroup Γ so that the construction of the coset space could make sense. If Γ remains the same, the additional 2 dimensions can make the volume of the coset space infinite. Indeed, the constancy of $p_1 \cdot p_2$ eliminates one of the two infinitely large dimensions and leaves one.

   Could one allow a complexification of $SO(1,3)$, $SO(3)$ and $SO(1,3)_c/SO(3)_c$? Complexified $SO(1,3)$ and corresponding subgroups Γ satisfy $OO^T = 1$. Γ_c would be much larger and contain the real Γ as a subgroup. Could this give rise to a complexified hyperbolic manifold H_c^3 with a finite volume?

3. A good guess is that the real part of the complexified bilinear form $p \cdot p$ determines what tachyonicity means. Since it is given by $Re(p)^2 - Im(p)^2$ and is invariant under $SO_c(1,3)$ as also $Re(p) \cdot Im(p)$, one can define the notions of time-likeness, light-likeness, and space-likeness using the sign of $Re(p)^2 - Im(p^2)$ as a criterion. Note that $Re(p)^2$ and $Im(p)^2$ are separately invariant under $SO(1,3)$.

   The physicist's naive guess is that the complexified analogs of infinite discrete and discontinuous groups and complexified hyperbolic manifolds as analogs of Fermi torus exist for $Re(P^2) - Im(p^2) > 0$ but not for $Re(P^2) - Im(p^2) < 0$ so that complexified dS manifolds do not exist.

4. The bilinear form in H_c^3 would be complex valued and would not define a real valued Riemannian metric. As a manifold, complexified hyperbolic manifold is the same as the complex hyperbolic manifold with a hermitian metric (see `https://cutt.ly/qVsdS7Y` and `https://cutt.ly/kVsd3Q2`) but has different symmetries. The symmetry group of the complexified bilinear form of H_c^3 is $SO_c(1,3)$ and the symmetry group of the Hermitian metric is $U(1,3)$ containing $SO(1,3)$ as a real subgroup. The infinite discrete subgroups Γ for $U(1,3)$ contain those for $SO(1,3)$. Since one has complex mass squared, one cannot replace the bilinear form with hermitian one. The complex H^3 is not a constant curvature space with curvature -1 whereas H_c^3 could be such in a complexified sense.

2.2 Topological condensed matter physics and TGD

Topological considerations have become an essential part of condensed matter physics. In condensed matter physics the topology of patterns of order parameters and of Fermi surface play a key role. In the TGD framework the topology of space-time surface in X^4 and the dual 4-surface in M^8 having an interpretation as an analog of momentum space are non-trivial and the question how this could reflect itself in condensed matter physics.

2.2.1 Topology of the energy bands in solids

The notions of 2-D face states, edge states, and corner states seem to be behind many topological states. It is interesting to see what they could correspond to in the TGD framework.

One can imagine two alternative guesses.

1. At H level 4-surfaces as analogous to 4-D complexified momentum space are algebraic surfaces, that is 4-D "roots" of polynomials.nThese algebraic surfaces have singularities at the level of H mapped to singularities at the level of H. They can have corners, edges, and

intersection points, 2-D singular surfaces. At the level of H they correspond to strings, string world sheets, and light-like orbits of partonic 2-surfaces: in this case the line singularity is blown up to a 3-D singularity.

2. These singularities need not however correspond as such to the above listed singularities since the active points of cognitive representation defined by mometa which are algebraic integers do not correspond as such to the physical states. Rather, physical states are Galois confined bound states of quarks for a given extension of rationals and it is the energy and momentum spectrum of these states which is relevant.

The second guess is based on the idea that the energy bands correspond to substructures formed by discrete 4-momenta of Galois confined states.

1. Cognitive representation consists of momenta for which momentum components are algebraic integers. Some of these points are occupied by quarks, they are "active" (this brings in mind Bohm's notion of active information).

   Physical states must have total momentum which is rational integer using the unit defined by the largest CD involved defining IR cutoff. Smallest CD defines the UV cutoff. This means Galois confinement in momentum degrees of freedom. Same happens also in spinorial degrees of freedom.

2. Bloch waves are of the form $exp(ikx)u(x)$ where u is a periodic function with the periods of lattices and k is continuous pseudo-momentum. k can be restricted to the first Brillouin zone defined as the counterpart of a lattice cell in momentum space. For Bloch states the translational symmetry is broken down to a discrete subgroup of the translation group acting as symmetries of lattices and therefore of u.

   For Bloch waves, the wave vectors and also energies would be quantized by periodic boundary conditions which would mean in the TGD framework that the momenta are integer valued using a suitable unit. The phase factors $epx(iknL)$ would be roots of unity and therefore number theoretically universal. This requires that $kL = m$ is a rational integer.

3. Mass shells as hyperboloids $H^3(m)$ are of special interest as are also the 3-D M^4 projections of 6-D universal brane-like entities. The latter are 3-surfaces $E = E_n$ where E_n is the root of the polynomial defining the 4-surface in M^8. Hyperboloid allows tessellations and the Euclidean 3-space E_3 defined $E = E_n$ surfaces inside light-cone allows lattices expected to emerge naturally from Galois confinement.

4. This picture suggests that each $E = E_n$ shell gives rise to real energy shells with rational integer valued energy and momentum components as sums of the multiples of algebraic integers for quarks. The allowed momenta for given total energy would correspond to states assignable to a given total energy analogous to a given $E = constant$ 2-surface of an energy band. The singular topologies could correspond to intersections or touchings of these bands.

One cannot exclude the possibility that the states with quarks with momenta at the singular pieces of 4-surfaces (touching along 0,1, or 2-D surface) could correspond to these singularities. For instance, the touching of two energy bands could correspond to this kind of singularity.

The article of Carpentier [D3] gives a nice introduction to the topology of bands in solids and it is interesting to see the situation from the TGD point of view. Topological insulators, semimetals, so called Majorana fermions, etc. involve singular situations in which energy bands touch each other and the question is what this means at the level of M^8.

Can one have a situation in which different energy bands touch each other at a single point or possibly along 1-D or 2-D (discrete) surfaces? The discussion is very similar for mass shells $H^3(m)$ and energy bands $E^3(E_n)$ so that only the case of E^3 is discussed.

1. Consider first energy bands E_n. For a given mass m, one obtains a set of energies E_n corresponding to the roots of P. When two roots co-incide, entire energy bands coincide. This would be however the situation for single quark states which are not possible by Galois confinement for irreducible polynomials with rational coefficients.

2. Two Galois confined states belonging to different energy bands E_n have energies, which are sums of the integer combinations of rational parts of energies E_n of single particle states. These sums are identical for some states associated with E_n and E_n.

   One can imagine that these bound states energies are the same for two different values of E_n so that bands formed by bound states can touch. Even higher-dimensional intersections can be considered. Similar situation might occur for the Galois confined states associated with different mass hyperboloids.

3. In condensed matter situation momenta are defined only modulo the addition of lattice momentum, which is multiple of $\hbar_{eff}/a = N\hbar_{eff}/L$ where a and L are UV and IR length scale cutoffs defined by the smallest and largest CDs. This condition would loosen the conditions for touching.

2.2.2 Topological insulators in the TGD framework

There is a nice summary by Suichi Murakami about topological insulators [D26] helpful for a newcomer to the field.

Let us summarize the basic physical properties of spin waves.

1. Topological insulator is an insulator in the bulk and therefore has a gap between valence and conduction bands. TIs have conducting surface states, which can be edge states for 2-D TIs and surface states for 3-D TIs (Dirac cone in momentum space). The edge/surface states correspond to edges/surfaces in x-space. Fig. 1 of [D26] `https://cutt.ly/yRGDV1U`) provides an illustration of edge and surface states. As Fig.3 associated with a simple model for surface states illustrates, edge and surface states have a finite penetration depth to the bulk.

   For 2-D TIs, valence and conduction bands touch in 1-D k-space (see Fig. 2 of `https://cutt.ly/yRGDV1U`), which also illustrates the Dirac cone). The states with degenerate energies correspond to pairs of electrons with opposite spins and momenta related by the condition $k_1 = -k_2$ modulo lattice momentum. The electrons at opposite edges/surfaces move in opposite directions and have opposite spins. The net charge current vanishes but there is net spin current.

2. Spin orbit coupling is present. Orbital momentum is mathematically like magnetic field B effectively replaced with angular momentum L. The analog of torque for B is replaced with torque $s \times L$. This gives rise to counter propagating opposite spins and spin currents.

3. For TIs, T is not violated but PT and P are violated. The presence of magnetic fields breaking T thus destroys the edge/surface conductivity. The states are helical and have no definite parity since P changes the helicity. Superposition of states with opposite momenta and spins occurs so that spin current is formed. By the absence of magnetic field back scattering destroying the conductivity is not possible since this would require change of both spin direction and momentum direction.

   Spin orbit $(L \cdot S)$ interaction is required for the formation of spin currents. L comes from the rotational motion of electrons along the surface or edge; it tends to turn L and S in the same direction so that spin waves emerge.

4. Z_2 topological quantum number Z is conserved and reflects time reflection invariance. Z can be understood from the graph of energy at the conduction band, which has suffered splitting due to the spin orbit interaction so that energy is reduced in the conduction band. The graph of energy has two topologically non-equivalent forms. The graph either connects valence and conduction bands or not. In the latter case one has an ordinary insulator (I). In the first case one has TI.

   For I, the graph has 2 or 0 intersections with the graph for the lower energy of the spin-slit state. TI has only one intersection. Perturbations invariant under time reversal do not affect the situation. More general formulation for the Z_2 invariance is in terms of the odd/even character of intersections.

Could TGD add something interesting to the notion of TI?

1. Mathematically the spin-orbit interaction is analogous to that between magnetic moment and magnetic field except that it couples orbital motion and spin and forces the correlation between spin direction and momentum and therefore the formation of a spin wave. Magnetic field does not cause this although it would parallelize spins with itself.

2. In Quantum hydrodynamics (QHD) according to TGD [L51], the circular orbital motion could be accompanied by a Kähler magnetic field in the direction of angular motion possibly assignable to a monopole flux tube.

   Could this make sense now? There would be 2 magnetic fields of opposite direction associated with the two directions of rotation of electrons. They should reside at different space-time sheets. At QFT limit the net B would vanish but make itself visible as a spin current. The effect could be therefore seen as evidence in favour of many-sheeted space-time.

3. One can also consider variants of this picture. Kähler magnetic field at flux tubes would be an essential element. This can come from both M^4 and CP_2 and one can ask whether only M^4 contribution is present. Velocity of current flow would be proportional to Kaehler gauge potential which would be of opposite sign a 2 space-time sheets. This would not break T at the QFT limit.

   Note that neutrinos would experience this contribution and this provides an experimental test: could the strange behavior of solar solar neutrinos and also in laboratory be understood in terms of M^4 Kähler field in Sun or in laboratory?

2.2.3 Discrete symmetries at the level of M^8

Discrete symmetries T, PT, and CP and their violations are closely involved with the phenomena of topological condensed matter physics. The challenge is to understand T, PT, and CP violations at the level of M^8.

The definition of discrete symmetries in $H = M^4 \times CP_2$ was discussed already in my thesis [K1] [L2] about TGD. In particular, geometrically C corresponds to a complex conjugation in CP_2. At the level of M^8, these discrete symmetries should allow a realization as symmetries of the polynomials defining the space-time surface.

P changes the direction of 3-momenta. The counterpart of the Fermi surface should therefore become reflection asymmetric in the violation of P. The reflections are with respect to the middle point of the CD. T changes the sign of energy and half cones of CD in H and mass shells with opposite sign in M^8 are permuted. Also the time reversed classical time evolutions are different if T is violated. One can ask whether the violation of P implies a compensating violation of T (by CPT)?

Both M^4 and CP_2 contributions to Kähler magnetic field could induce T violation and M^4 contribution could do this in long scales. If T violation takes place at the fundamental level, topological instanton term which is divergence of axial current appearing in Kähler action could induce it. The analogs of instantons induce a violation of the conservation of monopole charge. This is possible only if the M^4 projection of the space-time surface is 4-dimensional. Analogous statement applies in the case of CP_2 and CP_2 type extremals have indeed 4-D CP_2 projection.

C involves a complex conjugation and changes the signs of charges. What does this mean in M^8? The normal spaces of 4-surface in M^8 containing a preferred complex plane or having integrable distribution of them are labelled by CP_2 coordinates. They are mapped to their complex conjugates.

What happens to the polynomial defining the space-time surface? Polynomial itself is real and cannot change but its algebraic continuation to an octonionic polynomial can be different. Indeed, real function can be algebraically continued to a complex function or its conjugate.

1. The complexified octonions involve a commutative imaginary unit i. Complex conjugation with respect to i leaving the real polynomial invariant but leading to a complex conjugate of the 4-surface looks like a reasonable first guess. One can however argue that the conjugation with respect to i is associated with T.

Recall, that the proposal [L29] that co-associative 4-surfaces in M_c^8, having an interpretation as an analog of momentum space, correspond to 4-surfaces identifiable as roots of complexified octonionic polynomials yielded a cold shower. Due to Lorentz symmetry, naive counting of dimensions fails and one obtains 2 polynomial equations with complexified mass as argument stating that the mass squared is a complex root of the polynomial. The solutions correspond to common roots and are 6-D.

The solution of the problem would be that 4-surface is the intersection of 6-surface and its complex conjugate with respect to the commuting imaginary unit i. The common root must be real but the points in the intersection can be complex. Hence the action of T on X^4 is in general non-trivial and a spontaneous violation of T is possible at momentum space level.

2. Also octonions allow conjugation. In M^4 sector conjugations for octonionic units this would give rise to P and T. In the complement E^4 the conjugations for 2-D subspaces are also possible.

   Could C relate to the commutative normal spaces of 6-D surfaces labelled by points of the CP_2 twistor space $SU(3)/U(1)\times U(1)$. Could the complex conjugation in the 2-D $U(1)\times U(1)$ fiber of this space, correspond to C. The complex conjugation would therefore act on the (integrable distribution of) 2-D normal spaces of these 6-D surfaces and would not act in $M^4 \subset M^8$.

3. At the level of H, C and P are violated for the Dirac equation for a fixed H-chirality of quarks spinors and also for the modified Dirac equation, which corresponds to the octonionic Dirac equation in M^8. Also CP is violated for the modified Dirac equation in H if the action contains topological Kähler instanton terms. This violation should have a counterpart for the octonionic Dirac equation. Since this equation selects a single point at 4-surface, the CP violation for the 4-surface could induce CP violation.

2.2.4 Instantons in the TGD framework

Instantons induce violations of CP and therefore of T in gauge theories such as QCD.

It is interesting to consider the interpretation of Q as an instanton number.

1. Montonen-Olive duality (https://cutt.ly/HE6gMX6) is associated with a gauge theory in which magnetic and electric charges are rotated so that the coefficient of YM action in the action exponential is replaced with the quantity $\tau = \theta/2\pi + 4\pi i/g^2$.

2. τ is invariant under modular transformations $SL(2,Z)$ generated by a shift $\tau \rightarrow \tau + 1$ and $\tau \rightarrow 1/\tau$. The inversion symmetry has strong implications for the understanding of the strong coupling phases of quantum field theories, in which magnetic monopoles replace particles as elementary objects.

3. In the gauge theory θ is analogous to momentum. The vacuum state is plane-wave like superposition $\sum_N exp(iN\theta/2pi))|N\rangle$ of vacuum states differing by a topologically non-trivial gauge transformation as a map $S^3 \rightarrow G$. Note that ball B^3 is effectively S^3 if the gauge transformations are trivial at its boundary. The homotopy equivalence classes of gauge transformations are labelled by the winding number N. N characterizes instantons changing the magnetic charge by N units so that the ground state is a superposition of states with varying values of N transforming by a phase factor under a topologically non-trivial gauge phase transformation.

Consider now the situation in the TGD framework.

1. There are differences between TGD and gauge theory context. Gauge group is replaced with $U(1)$ having a trivial third homotopy group.

   Could a localized version of the quaternionic automorphism group $SO(3)$ serve as a counterpart of a gauge group. The surfaces in M^8 can be indeed thought of as maps from M^4 to the quaternionic automorphism group G_2.

2. The non-trivial gauge transformations - $U(1)$ instantons - are clearly possible. The non-trivial gauge transformation could correspond to a tological non-trivial gauge transformation $A+nd\phi$, where ϕ is angle coordinate around axis going through a line singularity as a puncture in 3-space associated with the time-like line connecting the tips of CD. Note however that color gauge action reduces to the Kähler action so that both interpretations might make sense.

3. Kähler action generalizes to

$$S_K = \frac{1}{\alpha_K} \int J \wedge *J\sqrt{g} - \frac{(}{i}\theta/2\pi) \int J \wedge J\sqrt{g} \ . \quad (2.1)$$

   Since only the exponent of S_K matters in the vacuum functional, I contributes a non-trivial phase factor to the Kähler function only for $exp(i\theta/2\pi) \neq 1$ ($\theta \neq n2\pi$). One can assign θ to both M^4 and CP_2 parts of Kähler action. The value of instanton term characterizes the non-conservation of the axial (monopole) current having instanton term as divergence.

   If one assumes self-duality of the gauge field true for instantons interpreted as gauge fields in S^4, the action reduces to ordinary Kähler action with coefficient proportional to τ. Interestingly, the quaternionic projective space M^4/Q can be regarded as S^4 so that Hamilton-Jacobi structures of M^4 proposed to serve as moduli space for the self-dual Kähler fields in M^4 could appear naturally.

4. $I(CP_2)$ is non-trivial due to the non-trivial homology of CP_2. $I(CP_2)$ gives a 3-D contribution, which appears at the boundaries between Minkowskian and Euclidean regions of the space-time surface as a topological Chern-Simons term and affecting the boundary conditions at the light-like orbits of partonic 2-surfaces in this way. These boundaries have interpretations as light-like parton orbits carrying quarks lines.

5. If CD contains a time-like "hole" along the axis connecting the tips of CD, also $I(M^4)$ is non-trivial. One can imagine extremals for which a genuine hole in the metric sense is generated along the M^4 time axis. What is required is that the induced metric using M^4 coordinates is of the form $dt^2 - dr^2 - (r^2 + r_0^2)d\Omega^2$. These holes should correspond to "blow-ups" of singularities of the algebraic surface in M^8. Now the 3-D tangent spaces would have no special direction at the singular points. For CP_2 type extremals the same would hold true at the level of M^8. Could this "hole" be the TGD counterpart of the blackhole of GRT and could it serve as a signature of CD?

6. $J^\wedge J$ is non-vanishing only if the M^4 *resp.* CP_2 projection is 4-D. This does not guarantee self-duality unless also the induced metric reduces to the metric of M^4 *resp.* CP_2. This is true for the canonical embedding of M^4 and for CP_2 type extremals having light-like M^4 projection. Self-duality is true for the Kähler forms of M^4 and CP_2 but not for the induced Kähler forms $J(M^4)$ and $J(CP_2)$. Therefore classical gravitation breaks the self-duality and Montonen-Olive duality in the TGD framework. The possibility of extremals with M^4 and CP_2 projections smaller than $D = 4$ implies that θ is effectively vanishing for them.

$\theta(M^4)$ and $\theta(CP_2)$ as fundamental parameters obeying number theoretical coupling constant evolution would imply a violation of CP symmetry in both M^4 and CP_2 sector. Are the instanton terms present at the fundamental level or are they present only at the QFT limit and induced as a description of spontaneous violation of CP and T? Indeed, as in the condensed matter systems, CP violation could be caused by the magnetic part of the generalized Kähler action even without instanton term.

1. The strong CP problem of QCD is due to instanton inducing an instanton term in effective color YM action. The parameter characterizing the violations should be very small.

   In the TGD framework, a proposal for a solution of this problem could be that the counterpart of the color gauge field does not allow instantons. Here one must be cautious however. The components of the proposed classical color gauge field are proportional to the products of

Hamiltonians of color isometries and Kähler form and instanton terms for the induced Kähler form would induce a CP violation. Indeed, Kähler action can be also regarded as a color gauge action and therefore instanton term makes sense for it.

2. Could $\theta(M^4)$ and $\theta(CP_2)$ induce a CP violation consistent with the observed CP violation in hadron physics or does one encounter the strong CP problem also in the TGD framework?

   If hadrons are string-like objects, they correspond to flux tubes as deformations of strings. For deformations with dimension $D < 4$, instanton term vanishes. Could this be the reason for the small violation of CP at the level of M^4? For CP_2 type extremals, $I(CP_2)$ is non-vanishing but equal to the Kähler action and non-dynamical for the basic CP_2 type extremals since dynamics in in M^4 degrees of freedom with CP_2 taking the role of arena of physics. Could these effects make the hadronic CP violation small?

3. Matter-antimatter asymmetry is a CP violation, which does not look small at all. If the mechanism is actually a small CP violation implying that rate for the condensation of anti-quarks to leptons is slightly larger than that for the condensation of quarks to antileptons, the matter antimatter symmetry could emerge during a very early period of the cosmic evolution when leptons were formed.

4. There are also further questions. Could the QCD instantons have TGD counterparts as Hamilton-Jacobi structures and also as analogs of S^4 instantons in the quaternionic projective space of octonions which would be 4-D mass hyperboloid H^4 as Minkowski analog of S^4 but with space-like signature. Could the parameter θ in the instanton term of Kähler action induce the formation of the ground state (θ vacuum) as a superposition of space-time surfaces with various instanton numbers in the sector of WCW consting space-time surface with 4-D M^4 and/or CP_2 projection?

2.3 The new view about classical fields

The TGD view about classical gauge fields differs in many aspects from the Maxwellian and gauge theory view since the classical fields associated with the system define a geometric what I call its field body (magnetic body (MB)) is the term that I have used. MB can carry also electric fields very closely related to magnetic fields unless the corresponding space-time surface is static. MB consists of flux tubes and flux sheets.

There are 2 kinds of cosmic strings: with monopole flux (see **Fig. 15**) or without it. The simplest cases correspond to Y^2, which is either a homologically non-trivial or trivial geodesic sphere of CP_2.

This predicts two kinds of magnetic flux tubes and two kinds of magnetic and electric fields. This suggests a possible interpretation for the fields H, M, B appearing in Maxwell's theory as field H carrying monopole flux requiring no current as source, magnetization M as non-monopole part induced by H , and $B = H + M$ as their sum experienced by test particle in many-sheeted space-time. The same would apply to D, P and E. If this interpretation is correct, TGD would have been secretly present in Maxwell's theory from the beginning.

The proposal that MB serves as a seat for dark matter as $h_{eff} = nh_0$ phases is central in the TGD inspired theory of consciousness and living matter. MB would be the boss and receive sensory input from ordinary biomatter and control it. This would happen in terms of dark photons with frequencies in EEG range and also in other ranges. The energies would be in the visible and UV range assigned to biophotons to which the dark photons would transform.

Magnetic flux tubes could accompty quantum vortices appearing in various macroscopic quantum phases. Even the hydrodynamical vortices in macroscopic scales could correspond to quantum coherent magnetic flux tubes with a large value of h_{eff} acting as a master forcing the coherent dynamics or ordinary matter. In hydrodynamics the classical Z^0 magnetic field, which in situations allowing skyrmions, is proportional to the induced Kähler form, could be important. Large parity breaking effects would be the prediction.

Also the view about radiation fields changes. Massless extremals (MEs)/topological light rays are counterparts for massless modes. They allow a superposition of modes with a single direction of massless momentum. The ordinary superposition of gauge potentials in gauge theory is replaced with union of space-time surfaces with common M^4 projection. The test particle experiences the sum of gauge potentials associated with various space-time sheets so that the gauge potentials effectively superpose. Ideal laser beam is a convenient analogy.

MEs are ideal for precisely targeted communications without dispersion and dissipation. MEs are soliton-like entities and one can ask whether MEs could provide a model for solitons or accompany solitons. TGD based model for nerve pulse involves Sine-Gordon solitons with large h_{eff} assigned to the cell membrane and dark Josephson radiation would have MEs as space-time correlate [K31, K15, K32].

MEs do not allow standing waves possible in Maxwell theory but a set theoretic union of parallel MEs can effectively give rise to standing waves. Lorentz transformations give rise to waves moving with arbitrary sub-luminal velocity. Even a superposition in which fields effectively sum up to zero but there is a non-vanishing energy density as sum of energy densities for the two MEs, is possible.

2.4 About quantum criticality in TGD

In TGD number theoretical vision about physics brings a new view about quantum criticality.

1. Quantum criticality is actually the basic assumption of TGD: the Kähler coupling strength α_K appearing in the classical action principle of TGD would be analogous to a critical temperature and have a discrete spectrum. This would make the theory unique. All space-time sheets are quantum critical but at QFT limit this is of course masked by the replacement of sheets with a single region of M^4 made curved.

2. At the number theoretical M^8 side there is no action principle. The universality of the dynamics could be seen as a manifestation of quantum criticality. Can α_K emerge at M^8 level somehow from scattering amplitudes in M^8 and have a number theoretical origin [L47].

   At the level of H coupling constants are visible only at the level of frames defining the space-time as an analog of soap film. The parts of the frame are images of singularities for the X^4 in M^8. The challenge is to understand how the singularities of the space-time surfaces determine α_K already at the level of M^8?

   p-adic thermodynamics for mass squared predicts a spectrum of temperatures with values coming as inverse integers [K19, K9]. Also this temperature quantization could be seen as a counterpart for the quantum criticality.

3. Quantum criticality involves long range correlations and the hierarchy of Planck constants characterizing them [K11, K12, K13, K14]. h_{eff} corresponds to a dimension of extension of rationals characterizing the space-time surfaces. At criticality there is quantum superposition of space-time surfaces with various values of h_{eff} corresponding to polynomials defining the X^4 and one value of h_{eff} is selected in state function reduction.

2.5 What infinite-volume limit could mean in TGD?

Infinite volume limit corresponds to both thermodynamic and QFT limit and should be understood in the TGD framework. The questions are what it means if the infinite volume limit is actually realized and whether this has practical consequences.

1. At the level of ZEO infinite volume limit means that the size of causal diamond (CD) as an analog of Nature given quantization volume becomes infinite. The scattering amplitudes coded by zero energy states conserve Poincare quantum numbers at this limit.

2. At the level of H the volume action vanishes since the p-adic length scale dependent cosmological constant $\Lambda \propto 1/L_p^2$ approaches zero at the limit when the p-adic length scale L_p characterizing the X^4 becomes infinitely large.

   If $\Lambda = 0$ phase is real, the action would reduce to mere Kähler action containing both M^4 contribution and CP_2. In this case, one would also have extremals of form $X^2 \times Y^2$ for which CP_2 projection if the Lagrangian manifold with vanishing induced Kähler form. These extremals receive a negative contribution to energy from M^2. Could the preferred extremal property exclude these solutions?

Remark: If the sign of M^4 Kähler action is changed, the electric contribution to energy is positive and magnetic contribution negative. For string- like objects this would guarantee positive contribution.

3. In the number theoretic picture infinite volume limit in H could mean that polynomials defining $X^4 \subset M^8$ mapped to H are replaced with analytic functions with rational coefficients.

   Polynomials are assumed to vanish at origin (this guarantees that roots are "inherited" in their functional composition) and so should also the analytic functions. The inverse 1/f is infinite at origin and does not belong to the set so that one does not have a function field. Since one has only multiplication, one can speak about functional primes as in the case of polynomials.

   One can ask whether they should satisfy conditions guaranteeing that they can be regarded as polynomials of infinite order. Could one speak about polynomials of infinite degree as the limit of functional composites of polynomials with finite degree. As a matter of fact, infinite Galois groups are profinite groups and this requires this kind of inverse limit definition [L41].

   A concrete example is provided by the iteration of a polynomial of finite degree [L41]. In this case the spectrum of roots contains a continuous part at the limit so that complex numbers as completion of rationals would emerge at the infinite volume limit much like the continuum spectrum of momenta emerges from a discrete spectrum.

2.6 The notions of geometric phase, Berry curvature, and fidelity in TGD?

Non-contractible ground state Berry phase in the loop over the parameter space is associated with QPTs and is associated Berry curvature defining non-trivial U(1) holonomy (`https://cutt.ly/RWy7Deq`) Geometric phase (`https://cutt.ly/6Wy7GIT`) is a more general notion. It can be associated with homotopically non-trivial loops. For homotopically trivial loop geometric phase is due to non-trivial holonomy manifesting itself as Berry curvature. The Aharonov-Bohm effect represents an example about non-trivial holonomy. Electrons pass along paths closing together a region containing a magnetic field, which vanishes at the paths. Berry phase can be associated with loops in the parameter space for the Hamiltonian modelling the system.

Fidelity [D30] `https://cutt.ly/VWy5sVj`) defines a metric in the space of parameter dependent quantum states. It could be induced from metric of the parameter space. The abrupt changes of fidelity serve as a signature of quantum criticality.

Is this possible at the level of WCW?

1. WCW is a Kähler manifold [K33, K17]. Finite-dimensional Kähler manifolds have a trivial homotopy group. Complex coordinates of WCW contributing to Kähler form and metric correspond to complex coordinates. In these degrees there should be no homotopically trivial loops so that topological phase is not possible. The curvature of the Kähler form can however have effects.

2. The remaining degrees of freedom are zero modes and define the analog of the base space in bundle theory. They appear as parameters - essentially classical background fields - in the Kähler metric and Kähler form. The topology in the zero modes can have non-trivial homotopy. Geometric phase could be assigned with homotopically trivial loops in the zero modes.

   At the infinite-volume limit the sub-WCW defined by the degenerate ground states with a Lagrangian manifold Y^2 as CP_2 projection (vanishing Kähler form and color gauge fields but non-vanishing weak gauge fields) is highly interesting. The preferred extremal property could exclude these space-time surfaces.

It seems that TGD could provide a unified description of all these exotic quantum coherent phases.

2.6.1 How the description in terms of Berry phase and fidelity could relate to TGD?

Consider first the identification of the TGD counterparts of Berry phase and fidelity.

1. In TGD the ground states are defined as space-time surfaces/3-surfaces and quantum states are their superpositions. The Kähler metric defines the analog of the quantum metric and the Kähler form corresponds to Berry curvature.

   The fidelity of two quantum states $\Psi(\lambda)$ and $\Psi(\lambda+\delta\lambda)$ is defined as the overlap $\langle\Psi(\lambda)\rangle\Psi(\lambda+\delta\lambda)\rangle$ in parameter space. The fidelity for nearby states is expected to change dramatically at singularity.

   Fidelity at the level of WCW - rather than WCW spinor fields representing quantum states - would mean disappearance of appearance of quantal WCW degrees of freedom as zero models transform to dynamical quantal degrees of freedom or vice versa. This change would make itself visible at the level of quantum states whose inner product depends on the WCW Kähler metric.

2. WCW also allows spinor connection with some gauge group acting as non-abelian holonomies. This corresponds to non-Abelian Berry phase Kac-Moody algebras of H isometries are an excellent candidate in this respect. WCW allows super-symplectic group as isometries.

3. WCW metric has also zero modes, which do not contribute to the WCW metric. Any symplectic invariant associated with X^4 defines such an invariant and the induced CP_2 Kähler form is invariant under the symplectic transformations of CP_2 and can be said to define a continuum of this kind of invariants. This could induce a geometric phase, which is not due to a holonomy but non-trivial homotopy.

   Kähler magnetic fluxes over 2-surfaces define such invariants. For closed surfaces these invariants reduce to quantized magnetic fluxes. Also M^4 Kähler form defines such invariants. At the boundary of CD the sphere S^2 (light-like radial coordinate =constant) has symplectic structure and also this defines solid angles assignable to 3-surfaces as seen from the tip of the CD as invariants.

2.6.2 Could the singularity of the quantum metric relate to number theoretical physics?

The singularity of the quantum metric would mean a reduction of the number of the dynamical quantum degrees of freedom contributing to the WCW metric meaning that the rank of the WCW metric tensor decreases. At criticality complex coordinates would transform to zero modes. Some complex coordinates of WCW would reduce to real coordinates. This would correspond to quantum criticality. In a concrete mechanical system some eigen modes would vanish and corresponding frequencies would become zero.

Since the TGD Universe is quantum critical and this is expected to be a generic phenomenon. Quantum criticality involves long range fluctuations which would correspond to large values of h_{eff} and therefore space-time surfaces which are algebraically complex. Could these long range fluctuations relate to almost zero modes with small frequencies and large wave lengths?

These phase transitions could be number theoretic. They would change the polynomial defining the X^4 (recall that quantum state is the superposition of space-time surfaces in ZEO). The dimension n for the extension of rationals is equal to the order of the Galois group and would change. Galois symmetries would act as zero mode symmetries. The dimensions of the representations of the Galois group in terms of quarks would also change. The change in the number of degrees of freedom would change the fidelity.

n defines also the algebraic dimension of the integers extended to algebraic integers for extension as a space regarded as a ring of integers. If algebraic integers can define components of the momenta, the dimension of the momentum space with integer components of momentum increases from 3 to $3n$ as the dimension of the Galois group increases by factor n. This increase occurs in the transitions in which the polynomial Q defining the space-time region is replaced with $P \circ Q$ such that P defines n-dimensional extension.

This would have rather dramatic effects since the radius of the Fermi ball with radius would be reduced by factor $1/n$ and could contain the same number of states as ordinary Fermi ball: this would mean an increase of density by factor n^3 corresponding to n sheets. Quasicrystal structure in both $X^4 \subset M^8$ and its images in $X^4 \subset H$ is also suggestive.

2.6.3 Does infinite volume limit have spin-glass type degeneracy?

One can look at the situation also at the infinite volume limit. At the infinite volume limit the action is expected to reduce to Kähler action. Whether this implies ground state degeneracy depends on whether preferred extremal property allows it.

1. In the original picture there was only CP_2 contribution to Kähler action. This implies huge vacuum degeneracy of CP_2 Kähler action. Any X^4 with CP_2 projection which is 2-D Lagrangian manifold is a vacuum extremal. WCW metric becomes singular if its inverse does not exist: this means singularity and the existence of zero modes. 4-D spin variant of glass degeneracy (`https://cutt.ly/ORuZfgu`) and classical non-determinism emerge. Classical non-determinism does however not look physically acceptable.

2. The twistor lift forces the Kähler action to have also an M^4 part obtained by analytical continuation from E^4. Does the resulting Kähler action have ground state degeneracy at infinite volume limit?

   The simplest extremals are of the form $X^4 = X^2 \times Y^2$, X^2 a minimal surface in M^4 and Y^2 a Lagrangian manifold in CP_2. Symplectic transformations in CP_2 degrees act like $U(1)$ gauge transformations on CP_2 Kähler gauge potential and do not affect either Kähler form nor the Lagrangian manifold property.

   Only the induced metric is affected so that the effects are purely gravitational. This gives rise to the ground state degeneracy. The area of CP_2 projection is not changed and the action is affected only by the change of the induced metric. Conserved quantities are modified only by gravitational effects and are non-vanishing. The extremals are deterministic and apart from gravitational effects one has a huge ground state degeneracy analogous to spin glass degeneracy.

   Apart from gravitation, the WCW Kähler metric receives contributions only from M^4 degrees of freedom, which are not affected under these deformations. Could one say that CP_2 degrees have transformed to zero modes?

3. One can also have surfaces $X^2 \times Y^2 \subset M^4 \times CP_2$ such that both X^2 and Y^2 are Lagrangian manifolds at infinite volume limit. These would be vacuum extremals. Preferred extremal property should exclude them. Could the interpretation be that all quantum degrees of freedom have transformed to zero modes?

4. One can invent objections against this proposal.

   (a) Negative energies might emerge from the electric energy in M^4 degrees of freedom. Electric field gives a negative contribution to energy density. Signature is Minkowskian for M^2 subset $M^2 \times E^2$. The M^2 part of Kähler form is obtained from its E^2 variant by multiplication with factor i. This might cause problems.

   (b) These surfaces are extremals but the preferred extremal property could fail since the needed 4-D analog of complex structure is missing since Y^2 as a Lagrangian manifold is not a complex surface of CP_2.

   (c) There is however also an argument in favor of this picture. Ordinary Maxwellian magnetic fields correspond to a homologically trivial geodesic sphere of CP_2 and they are Lagrangian submanifolds. Therefore one cannot exclude the proposal.

2.6.4 The parameters of the effective Hamiltonian from the TGD point of view

Could the parameters of effective Hamiltonians have counterparts at the level of WCW?

1. 4-surfaces as WCW points define parameters in the analogs of eigenvalues of observables. Both supersymplectic and Kac-Moody algebras have as parameters the parameters coding

the point of WCW and Kac-Moody algebra. Number theoretic coding of ground states based on the Galois group as a symmetry group and p-adic primes defining p-adic length scale is what comes to mind.

The preferred 4-surfaces would naturally correspond to the maxima of Kähler function. It is quite possible that Kähler coupling constant is complex so that the complex number defining the exponent of Kähler function has phase $\pm pi/2$. The phase of the exponent is different and maxima are also stationary points. This would make possible interference effects central in QFTs. This is implied by the condition that classical conserved charges are apart from a phase factor real and can therefore be made real.

If M^8 space-time sheets are defined as "roots" of polynomials with rational coefficients [L29, L30], WCW becomes discrete and has the coefficients of polynomials as coordinates of a given point (X^4). An open question is why the maxima of Kähler function should correspond to rational polynomials with rational coefficients.

2. Super-symplectic transformations [K10, K33] as isometries of WCW are symmetries and can be regarded as a generalization of Kac-Moody type symmetries. The complex coordinate z and light-like radial coordinate r of the light-cone boundary are in the role of parameters. Analog of 3-D gauge group but gauge group replaced with the symplectic group of $S^2 \times CP_2$ is in question. The light-like orbits of partonic surfaces could naturally carry Kac-Moody algebra representations of isometries - at least at infinite volume limit.

   Non-negative conformal weights parameterize the representations of this algebra. The construction of states would be as follows. A sub-algebra $SCA_{n_{max}}$ with conformal weight larger than n_{max} and its commutator with the entire algebra annihilate states. Only the states with conformal weight smaller than n_{max} remain. Other degrees of freedom are effectively gauge degrees of freedom. n_{max} is expected to depend on the polynomial, its Galois group and degree. A huge reduction of degrees of freedom takes place. The remnant of the super-symplectic group would act as dynamical symmetries.

   Same could occur in the symplectic degrees of freedom labelled by Hamiltonians which are products of S^2 and CP_2 Hamiltonians. The only non-trivial normal subalgebra corresponds to isometries and states would be annihilated by the generators in the complement of this algebra.

   Rational coefficients of a polynomial defining the X^4 serve as the parameters characterizing the ground state. Higher level description is in terms of the Galois group which depends only weakly on the polynomial.

3. What about the description at the level of X^4? The solutions of modified Dirac action for induced spinor fields depend on the parameters characterizing the space-time surface.

2.7 Quantum hydrodynamics in TGD context

In the standard picture quantum hydrodynamics is obtained from the hydrodynamic interpretation of the Schrödinger equation. Bohm theory involves this interpretation. (`https://cutt.ly/cWy3O9Ts`).

1. Quantum hydrodynamics appears in TGD as an *exact* classical correlate of quantum theory [K4]. Modified Dirac equation forces as a consistency condition classical field equations for X^4. Actually, a TGD variant of the supersymmetry, which is very different from the standard SUSY, is in question.

2. TGD itself has the structure of hydrodynamics. Field equations for a single space-time sheet are conservation laws. Minimal surfaces as counterparts of massless fields emerge as solutions satisfying simultaneously analogs of Maxwell equations [L55]. Beltrami flow for classical Kähler field defines an integrable flow [L39]. There is no dissipation classically and this can be interpreted as a correlate for a quantum coherent phase.

3. Induced Kähler form J is the fundamental field variable. Classical em and Z^0 fields have it as a part. For $S^3 \subset CP_2$ em and Z^0 fields are proportional to J: which suggests large parity

breaking effects. Hydrodynamic flow would naturally correspond to a generalized Beltrami flow and flow lines would integrate to a hydrodynamic flow.

4. The condition that Kähler magnetic field defines an integrable flow demands that one can define a coordinate along the flow line. This would suggest non-dissipating generalized Beltrami flows as a solution to the field equations and justifies the expectation that Einstein's equations are obtained at QFT limit.

5. If one assumes that a given conserved current defines an integrable flow, the current is a gradient. The strongest condition is that this is true for all conserved currents. The non-triviality of the first homotopy group could allow gradient flows at the fundamental level. The situation changes at the QFT limit.

6. Beltrami conditions make sense also for fermionic conserved currents as purely algebraic linear conditions stating that fermionic current is a gradient of some function bilear in oscillator operators. Whether they are actually implied by the classical Beltrami conditions, is an interesting question.

7. Minimal surfaces as analogs of solutions of massless field equations and their additional property of being extremals of Kähler action gives a very concrete connection with Maxwell's theory [L55].

2.8 Length scale hierarchies

The length scale hierarchy associated with the hierarchy of Planck constants and p-adic length scale hierarchy lead to the proposal that one has quantum coherence and supra phase always realized in some scale and the loss of say superconductivity means only the reduction of this scale.

Also dark variants of valence electrons make sense and there is evidence for them. When looking at the definition of say exciton, one cannot avoid the impression that something is missing. Electrons and holes are assumed to have incredibly small effective masses. The very notion of effective mass is in conflict with the idea that one has a fundamental quantum theory description.

One also introduces in the Schrödinger equation dielectric constant which comes from macroscopic description. Why doesn't one do the same in the case of ordinary atoms. This kind of mixing of phenomenological descriptions with a fundamental description is to me a deadly sin.

One cannot avoid the crazy looking question whether exciton could be a valence electron which is dark with $h_{eff} = k \times h$ and binds with an atom. It would be automatically accompanied by a hole. The binding energies would be scaled like $1/k^2$ and one would obtain the energies which can be 3 orders of magnitude smaller than those for hydrogen.

2.9 A general model of macroscopic quantum phases

2.9.1 Hierarchy of quantizations at the level of WCW

Before saying anything about macroscopic quantum phases, one must define what many-particle states correspond at the level of WCW.

1. The combination of UP with $M^8 - H$ duality leads to the view that many particle states at the level correspond to many-fermion (quarks actually) such that the momenta of quarks correspond to momenta as points of $X^4 \subset M^8$ with components, which are algebraic integers. In TGD framework, where all particles, also bosons, are composites of fermions. At M^8 level Cooper pairs would correspond to pairs of occupied points of a mass shell $H^3 \subset M^8$. The image of the region of momentum space in H corresponds for quarks of given mass m corresponds to a region at the boundary of sub-CD with size given by Compton length $L = \hbar_{eff}/m$.

2. At the level of WCW, the analog of the many-quark state associated with a given quark mass corresponds to the analog of plane wave inside a large $CD \subset H$ defined by the smallest mass involve but with point-like particle replaces with space-time surface inside sub-CD (CD(m)) carrying zero energy state characterized by quark momenta at opposite boundaries of CD(m) having opposite sign of energy.

3. The entanglement between these states due to Fermi statistics is however maximal and SFRs are not possible. How can one construct entangled states. The answer is simple perform the analog of second quantization at the level of WCW. One can form the analogs of 2-particle states by taking two CDs with specified quark content and assign to both the analogs of plane waves. If the CDs correspond to different extensions of rationals so that the effective Planck constants are different, one can entangle these states in WCW degrees of freedom. One can construction N-particle states by using the same recipe.

4. To each many quark state one can assign odd or even boson number and regard this state as analog of elementary fermion or boson. This is what is indeed done quite generally. Could this operation have deeper meaning. Could one require that the many-quark operators indeed commute or anticommute mutually. This condition cannot hold true generally but could be posed as an additional condition to the physical states: the commutator/anticommutation would be proportional $h_{eff}I$, I identity matrix.

   This construction would be third quantization. And nothing prevents from performing also fourth quantization within even larger CD. This hierarchy of quantizations brings in mind the basic hierarchical structures of the TGD Universe: many-sheeted space-time characterized by p-adic and dark length scale hierarchies, and also the hierarchy of infinite primes which corresponds to a repeated second quantization of supersymmetric arithmetic QFT [K38] conjecture to correspond to the hierarchy of space-time sheets.

2.9.2 WCW description of BECs and their excitations as analogs of particles

Fermi statistics requires that the BEC correspond to a distribution of correlated momentum pairs with the sum of the momenta equal to the momentum of the boson. Cooper pairs also have binding energy so that the mass of the pairs is slightly smaller than the particle mass so that the Cooper pairs belong to different $H^3 \subset M^8$ than the free fermions.

For the excitations of BEC condensate giving rise to supracurrents and superflows, some momenta of fermions are different from the common momentum of BEC, usually larger than the common momentum of BEC. The image of excitation of BEC in H would be a pair at proper time=constant hyperboloid in H and the map of momentum to position would be linear inside $CD(m)$. BEC would look very much the same at both M^8 and H side of duality.

The space-time surface $X^4 \subset CD(m)$ should correspond to a minimal surface and to a generalized Beltrami flow defining an integrable coordinate along the flux lines. In the case of conserved current gradient flow (vortex flow is an example of this). All many-particle states would be of this kind in the scale of $CD(m)$. These multi-BEC states would be analogs of many-particle states and one would have many-particle states of BECs and their condensates, which could entangle in WCW degrees of freedom. For instance, the entanglement between geometric representations of Galois groups is possible. In the TGD inspired quantum biology the multi-BEC like states are proposed to play a key role [L32, L44].

2.9.3 Superconductivity and superfluidity in TGD framework

The TGD based view about superconductivity and fluidity [L39] differs in many respects from BCS theory.

1. In the BCS theory superconducting state does not have a well defined fermion number and this leads to a somewhat questionable notion of coherent state of Cooper pairs. The Bogobliubov transformation creates the diagonalizable oscillator operator basis by mixing creation and annihilation operators. The resulting operators create superpositions of electrons and holes.

   In the TGD framework, the interpretation would be that the hole actually corresponds to dark fermion with $h_{eff} > h$ at dark space-time sheet so that fermion number conservation is not lost. Bogoliubov operators would be replaced with superpositions of creation/annihilation operators associated with different space-time sheets and create states which are superpositions of state at the two space-time sheets.

Effective Hamiltonian would include diagonalizable kinetic parts assignable to both space-time sheets, and the terms quadratic in creation/annihilation operators breaking fermion number conservation would be replaced with pairs of creation and annihilation operators associated with different space-time sheets describing the transfer of electron between the space-time sheets.

2. In the BSC theory Cooper pairs are carriers of supra current. In the TGD framework, dark electrons at dark spacetime-sheets could be the carriers. The binding energy of Cooper pairs liberated in their formation would provide the energy needed to transform ordinary electrons to dark electrons (the energies of particle states typically increase with h_{eff}). This makes possible superconductivity driven by energy feed possible also above critical temperature.

3. Can one describe supra currents and supra flows in terms of a single space-time surface as the classical space-time view based on Beltrami currents would suggest? This would mean that supracurrent would correspond to a collection of momenta of dark electrons at $H^3 \subset M^8$ in the proposed TGD based model or collection of Cooper pairs with $h_{eff} = h$ as in the standard description. The current carriers would have fixed momenta at the two boundaries of $CD(m)$ corresponding to the analogs of initial and final state momenta. Is this all that one can say at the quantum level and is the description as a flow only a classical description. At quantum level one could only deduce the change of the positions for the group of particles defining the flow. This indeed conforms with the UP.

Update: I received a link to a highly interesting popular article with title "A Breakthrough Experiment Unlocking the Mystery of Unconventional Superconductivity" (`https://rb.gy/fs8ecn`). The article told about the work of Sarah Hirthe et al reported in the article "Magnetically mediated hole pairing in fermionic ladders of ultracold atoms" published in Nature [D9]. This work gives support for the TGD view of superconductivity.

TGD based view of unconventional superconductivity [K29, K30, L39] is based on the new view of quantum physics provided by new space-time concept and number theoretic vision predicting phases of ordinary matter behaving like dark matter and labelled by effective Planck constant $h_{eff} = nh_0$, which can be very large as compared to the ordinary Planck constant h. This the case for the gravitational Planck constant introduced originally by Nottale. This implies quantum coherence in long scales essential for superconductivity.

This view suggests that hole pairs are formed as the electron pairs are transferred to the magnetic flux tubes and become dark and therefore have a non-standard value of effective Planck constant. This creates hole pairs at the level of the ordinary matter and the motion of the dark electron pair corresponds to that for the hole pair. The electron pair goes to a pair of magnetic flux tubes and transversal fluctuations in the shape of flux tubes are essential in the transition to superconductivity . This picture is consistent with the reported findings.

The really important message is that dark matter in TGD sense can be detected as the absence of ordinary matter! Hole pair is a shadow Cooper pair of dark electrons.

2.9.4 WCW level is necessary for the description for purely geometric bosonic excitations

The quantum description of sound requires WCW description since the phonons as oscillations of relative position of particles cannot be described in terms of quark-antiquark pairs. The description of exotic supra flows like that associated with magnon BEC in say ^3He supra fluid allowing orbital magnetization requires WCW. A good manner to clarify thoughts is to look at what this means in the case of magnons.

1. Standard classical description (`https://cutt.ly/HRuZh53`) suggests a direction of magnetization M which has changed due to the presence of external field H. This leads to the Landau-Lifschitz equation for the magnetization.

   The Fock space picture about magnons is as a plane wave for which the argument is the position of spin whose direction has changed. The quantization is described by introducing a Hamiltonian for spins. The relationship between these descriptions is somewhat obscure.

2. In TGD the fermionic Fock space description is not possible. Bosonic creation and annihilation operators would be needed but one cannot construct bosonic operators with a vanishing fermion number from quarks. Therefore magnons should correspond to WCW degrees of freedom.

3. In the TGD description, M would correspond at space-time level to the magnetic field at a non-monopole flux tube and H possibly at a monopole flux tube inducing the magnetization. Magnons would correspond to magnetization waves, as kinks propagating along magnetic flux tubes for M. Magnon should correspond to space-time surface H and this would determine its M^8 pre-image. If these excitations behave like identical particles, one can assign to them wave vectors and classical momenta.

4. Also the notion of BEC makes sense at WCW level since one can construct the counterparts of genuine bosonic oscillator operators. Super-symplectic and Kac-Moody algebras of WCW acting at the boundaries of CD indeed include purely bosonic operators. Similar description at WCW level applies also to phonons as quanta.

   Cooper pair BECs allow approximate description in terms of fermion pairs with given total momentum but with members having different momenta. One cannot however exclude the possibility that there purely bosonic BEC at WCW level such that each Cooper pair is associated with a bosonic excitation of space-time surface.

3 Some concrete questions and problems

In this section some concrete questions relating to various applications of TGD to condensed matter physics are considered. Applications to (quantum) hydrodynamics is left to separate article.

3.1 Skyrmions in TGD framework

In hadron physics skyrmions (`https://cutt.ly/qRuXYMX`) appear at the level of momentum space. Proton as a skyrmion corresponds to a map of a 3-ball B^3 to $S^3 \subset E^4$ with non-trivial winding number. The points at the boundary are mapped to a single point so that B^3 effectively behaves like S^3. The map thus represents an element of third homotopy group and if this element is non-trivial one has skyrmions whose winding number has interpretation as number of protons. The radius of S^3 is the proton mass so that S^3 indeed lives in momentum space. $SO(4) = SU(2)_L \times SU(2)_R$ assigned to the current algebra picture of hadron physics acting as isometries of S^3 serves as the field space of skyrmions.

Skyrmions appear as topological defects also in condensed matter physics and correspond to 3-D magnetic field configurations inside B^3 and vanishing at the boundary of B^3 so that they define a map to S^3. In this case, the winding number of the map can correspond to the number of electron pairs. They appear in superconductivity, quantum Hall systems, liquid crystals, magnetic systems, and Bose-Einstein condensates (BECs). One example corresponds to ferromagnetic spin-1 Bose-Einstein condensates [D21](`https://cutt.ly/MWy3S5J`). Their universal appearance suggests that they could appear at fundamental level.

What TGD view would be following.

1. The proposal is that $M^8 - H$ duality allows to understand skyrmions as duality between the $SO(4)$ description of hadrons and $SO(4)$ symmetry group at M^8 level and QCD description in terms quarks and gluons and color $SU(3)$ at the level of H.

   In TGD framework skyrmions are associated with space-time surfaces in M^8 and skyrmion means a maps from a ball $B^3 \subset M^4$ to the sphere $S^3 \subset E^4$.The radius of S^3 is proton mass squared: this conforms with the interpretation of M^8 as momentum space.

2. Skyrmion in as a map $B^3 \rightarrow S^3 \subset E^4 \subset M^8 = M^4 \times E^4$ is mapped to a map $B^3 \rightarrow S^3 \subset CP_2 \subset H$ by $M^8 - H$ duality. The map $B_3 \rightarrow B^3$ is by inversion (Uncertainty Principle). The map would have a non-trivial winding number.

   What does the skyrmion sphere S^3 subset E^4 correspond to in CP_2. Recall that normal space of X^4 is mapped to a point of CP_2. The image of the Skyrmion looks like a graph for the normal space of $X^4 \subset M^8$ as a function of the point of X^4. How does the normal space correlate with the E^4 point at S^3? Continuity and single-valuedness look natural. The 3-sphere in X^4 is mapped to a D≤ 3 surface.

Essentially homotopy associating normal space characterized by a point of CP_2 to $S^3 \subset CP_2$ is in question. CP_2 has a trivial third homotopy group. The homotopy equivalence class is trivial unless one fixes the radius as is done also in the original model by fixing the mass to correspond to the radius of $S^3 \subset E^4$.

Could $S^3 \subset E^4$ containing the octonionic real axis be mapped to a sphere $S^3 \subset CP_2$ invariant under $U(2)$. At S^3 Z^0 gauge field is proportional to Kähler form J as is also the electromagnetic field [L1]. Therefore the long range correlations for Kähler form J are associated also with Z^0. Large parity breaking effects would become possible and indeed appear in living matter (chirality selection for biomolecules).

3. Could the sphere $S^3 \subset M^8$ mapped to $S^3 \subset CP_2$ related by M^8-H duality define a common denominator of several exotic condensed matter phenomena? $S^3 \subset M^8$ define a quaternionic 3-sphere and the automorphism group of quaternions. One can assign to skyrmions a flat $SO(3)$ gauge potential [D25] (`https://arxiv.org/abs/1812.07974`). Could this relate to the speculated emergence of $SO(3)$ as a synthetic gauge group [D8])(`https://cutt.ly/qWy3H9M`?

3.2 Dark matter and condensed matter physics

The following represents a collection of examples of possible applications of TGD view of dark matter to condensed matter physics.

3.2.1 Could one make dark matter visible?

Dark matter in TGD sense could make itself visible in many ways.

1. One can imagine diffraction by generating a dark photon or (dark) polariton beam using a laser beam providing the energy feed increasing h_{eff}. Dark photon beam would diffract from an analog of hole: the ordinary laser beam could represent the hole as a source of dark photons. The structure of dark matter at flux tubes involving flux tubes and their geometric patterns could become visibille in this manner.

   For instance, the braids formed by flux tubes could become visible. Here braid entropy is a central notion and central in TGD based view of hydrodynamics involving braiding in both time-like and space-like braiding [K3, K2, K40].

2. In quantum biology dark matter at magnetic body with large h_{eff} as measure for complexity and intelligence, serves as the boss controlling ordinary biomatter, and its quantum coherence forces ordinary coherence of ordinary biomatter, which cannot be understood in physics and chemistry based on ordinary quantum physics [L78].

Solids are either in crystal or amorphous phase. Long range order in crystals is lacking and this is visible in the X-ray diffraction pattern. The diffraction pattern [D27] (`https://cutt.ly/ZWyLgjk`) for a hyperuniform amorphous material is very different and is called highly exotic (see **Fig. 16**). Apart from forward scattering peak, the diffraction pattern involves no scattering for a considerable range of scattering angles. I cannot avoid the temptation to speculate.

1. Suppose that the proposed dark looking phases with $h_{eff} > h$ by their higher algebraic complexity (larger extension of rationals, larger Galois symmetries) control the lower levels in master slave hierarchy, in particular ordinary matter (now the amorphous film.

   Suppose that the scattering of say laser light feeding energy and increasing the value of h_{eff} creates dark photons or polaritons at this higher level. Suppose that polaritons scatter at flux tubes or flux sheets structures at higher level and eventually a transformation to ordinary photons occurs spontaneously. Could the interference of the scattered beam with incoming beam make the geometry of dark matter level visible as the example about scattering in hyperuniform matter would suggest?

2. This high level would have longer quantum coherence length and perhaps range order since h_{eff} is larger. The long range order would be visible in the scattering pattern. Could just this happen when laser light generates a polariton-exciton condensate [D20](`https://cutt.ly/4Wy8zi9`). Could one think of polariton vortex lattices [D17] (`https://cutt.ly/qWy8Zqf`) as counterparts of crystal lattices and could their presence become visible so that one could see dark matter.

   The polariton could correspond at flux tubes superposition of dark photon and of dark exciton identifiable as dark electron paired with ordinary hole formed when the electron was transferred to the flux tube. The photon component of the outgoing polariton beam formed by the transformation of dark photon to ordinary photon would reflect the structure of dark matter and flux tubes and leave the system as ordinary photons and generate the scattering pattern by interference.

3.2.2 A strange behavior of hybrid matter-antimatter atoms in superfluid Helium

I received an interesting link to a popular article "ASACUSA sees surprising behaviour of hybrid matter–antimatter atoms in superfluid helium" (`https://cutt.ly/NVIzglw`), which tells of a completely unexpected discovery related to the behavior of antiproton-^{4}He^{++} atoms in ^{4}He superfluid. The research article [D16] by ASACUSA researchers Anna Soter et al is published in Nature (`https://cutt.ly/LVIceiB`).

The formation of anti-proton-^{4}He^{++} hybrid atoms containing also an electron in ^{4}He was studied both above and below the critical temperature for the transition to Helium superfluid. The temperatures considered are in Kelvin range corresponding to a thermal energy of order 10^{-4} eV.

Liquid Helium is much denser than Helium gas. As the temperature is reduced, a transition to liquid phase takes place and the Helium liquid gets denser with the decreasing temperature. One would expect that the perturbations of nearby atoms to the state should increase the width of both electron and antiproton spectral lines in the dense liquid phase.

This widening indeed occurs for the lines of electrons but something totally different occurs for the spectral lines of the antiproton. The width decreases and when the superfluidity sets on, an abrupt further narrowing of He^{++} spectral lines takes place. The antiproton does not seem to interact with the neighboring ^{4}He atoms.

Researchers think that the fact that the surprising behavior is linked to the radius of the hybrid atom's electronic orbital. In contrast to the situation for many ordinary atoms, the electronic orbital radius of the hybrid atom changes very little when laser light is shone on the atom and thus does not affect the spectral lines even when the atom is immersed in superfluid helium.

Consider now the TGD inspired model.

1. It seems that either antiprotons or the atoms of ^{4}He superfluid effectively behave like dark matter. For the electrons, the widening however takes place so that it seems that the antiproton seems to be dark. In the TGD framework, where dark particles corresponds $h_{eff} = nh_0 > h$, $h = n_0h_0$ phases of ordinary matter, the first guess is that the antiprotons are dark and reside at the magnetic flux tube like structures.

   The dark proton would be similar to a valence electron of some rare earth atoms, which mysteriously disappear when heated (an effect known for decades) [L13]. Dark protons would indeed behave like a dark matter particle is expected to behave and would have no direct quantum interactions with ordinary matter. The electron of the hybrid atom would be ordinary.

2. Darkness might also relate to the formation mechanism of the hybrid atoms. Antiproton appears as a Rydberg orbital with a large principal quantum number N and large size proportional to N^2. $N > 41$ implies that the antiproton orbital is outside the electron orbital but this leaves the interactions with other Helium atoms. For a smaller value of N the dark proton overlaps the electronic orbital. Note that for $N = 1$, the radius of the orbital is $10^{-3}/8a_0$, $a_0 \simeq .53 \times 10^{-10}$ m, in the Bohr model.

3. The orbital radii are proportional to $h_{eff}^2 \propto (n/n_0)^2$ so that dark orbitals with the same energy and radius as for ordinary orbitals but effective principal quantum number $(n/n_0)N_d =$

N_{eff}, are possible. $(n/n_0)N_d = N_{eff}$ condition would give the same radius and energy for the dark orbital characterized by N_d and ordinary orbital characterized by N.

One can consider both dark-to-dark and dark-to-ordinary transitions.

1. The minimal change of the effective principal quantum number N_{eff} in dark-to-dark transitions would be n/n_0 and be larger than one for $n > n_0$. There is evidence for $n = n_0/6$ found by Randel Mills [D10] discussed from the TGD view in [L10]. In this case one would have effectively fractional values of N_{eff}. One can also consider a stronger condition, $h_{eff}/h = m$, one has $mN_d = N$. The transitions would be effectively between ordinary orbitals for which ΔN_{eff} is a multiple of m. This could be tested if the observation of dark-to-dark transition is possible. The transformation of dark photons to ordinary photons would be needed.

2. Energy conserving dark-to-ordinary transitions producing an ordinary photon cannot be distinguished from ordinary transitions if the condition $(n/n_0)N_d = N_{eff}$ is satisfied.

   The transitions $(37, 35) \to (38, 34)$ and $(39, 35) \to (38, 34)$ at the visible wavelengths $\lambda = 726$ nm and 597 nm survive in the Helium environment. The interpretation could be that the transitions occur between dark and ordinary states such that the dark state satisfies the condition that $(n/n_0)N_d = N_{eff}$ is integer, and that an ordinary photon with $\lambda = h/\Delta E$ is produced. This does not pose conditions on the value of h_{eff}/h.

   If the condition that $(n/n_0)N_d = N_{eff}$ is an integer is dropped, effective principal quantum numbers N_{eff} coming as multiples of n/n_0 are possible and the photon energy has fractional spectrum.

If this picture makes sense, it could mean a new method to store antimatter without fear of annihilation by storing it as a dark matter in the magnetic flux tubes. They would be present in superfluids and superconductors.

3.2.3 Mott insulators learn like living organisms

Researchers in Rutgers University have found that quantum materials, in this case Mott insulators, are able to learn very much like living matter (`https://cutt.ly/oTRZhQE`). The conductivity of the quantum material represented behavior and sensory input was represented by external stimuli like oxygen, ozone and light.

The finding was that conductivity depends on these stimuli and that the system mimics non-associative learning. Non-associative learning does not involve pairing with the stimulus but habituation or sensitization with the stimulus.

I have already earlier [K30] briefly considered transition metals, Mott insulators, and antiferromagnets from the point of view of TGD inspired theory of high Tc superconductivity.

1. By looking at Wikipedia (`https://cutt.ly/RTRXi22`), one finds that Mott insulators are transitional metal oxides such as NiO. Transition metals, such as Ni, can have unpaired valence electrons since they can appear in electronic configurations [Ar] $3d^8$ $4s^2$ or [Ar] $3d^9$ $4s^1$. This should make transition metals and their oxides conductors. They are not since they seem to somehow develop an energy gap between states in the same valence band making them insulators.

2. Mott developed a model for NiO as an insulator: the expected conduction was based on the transition for neighboring $Ni^{2+}O^{2-}$ molecules

   $$(Ni^{2+}O^{2-})_2 \to Ni^{3+}O^{2-} + Ni^{1+}O^{2-}$$

   .

   In the latter configuration, the number of valence electrons of Ni is odd for both neighbors.

3. The formation of the gap can be understood as a competition between repulsive Coulomb potential U between 3d electrons and the transfer integral t of 3d electrons between neighboring atoms assignable to the transition. The total energy difference between the two states is $E = U - 2zt$, where z is the number of neighboring atoms. A large value of U leads to a formation of a gap implying the insulator property.

4. Also antiferromagnetic ordering is necessary for the description of Mott insulators. Even this is not enough, and the rest which is not so well understood, is colloquially called mottism. The features of Mott insulators that require mottism are listed in the Wikipedia article. They include the vanishing of the single particle Green function along a connected surface in the first Brillouin zone and the presence of charge 2e boson at low energies.

5. The description of both Mott insulators and high Tc superconductors involves antiferromagnetism and Mott insulators exhibit extraordinary phenomena such as high Tc superconductivity and so-called colossal magnetoresistance thought to be due the interaction between charge and spin of conduction electrons.

In the TGD framework, the description of high Tc superconductors [K29, K30] [L39] involves pairs of monopole flux tubes with opposite direction of monopole magnetic flux possible not possible in Maxwellian electrodynamics. The members of Cooper pairs, which are dark in the TGD sense having an effective Planck constant $h_{eff} \geq h$, reside at the monopole flux tubes. The Cooper pairs are present already above Tc but the flux tubes are short and closed so that supercurrent flows only in short scales. At Tc long flux tubes are formed by reconnection.

Dark valence electrons could help to understand Mott insulators. Transition metals are known for a strange effect in which the valence electrons seem to disappear [L13] [L13] [K13]. The TGD proposal is that the electrons become dark in the TGD sense.

It has become clear that dark electron can appear only as bound states for which the sum of momenta, which are algebraic integers in the extensions of rationals with dimension $h = h_{eff}/h_0$ (this guarantees periodic boundary conditions) must be Galois singlets: one has Galois confinement. This implies that the total momentum is ordinary integer [L50, L52].

Therefore free dark electrons are not allowed and Cooper pairs and possibly also states formed by a larger number of electrons, say four as has been found [L50]) are possible as Galois singlets. In the TGD inspired quantum biology dark proton triplets realize genetic codons and genes could correspond to N-codons as Galois confined states of 3N dark protons [L44].

As a rule, single particle energies increase with increasing h_{eff} and the thermal energy feed could increase the effective value Planck constant for an unpaired valence electron of Mott insulator from h to $h_{eff} >= nh_0 > h$ of the valence electrons and it would become dark in the TGD sense. Here n denotes the dimension of extension of rationals assignable to the space-time region. The natural assumption is that Galois confinement forces the Cooper pairing of unpaired electrons of neighboring atoms.

Above Tc, the flux tubes associated with Cooper pairs would be too short for large scale superconductivity so that one would have a conductor or a Mott insulator. Under certain conditions involving low enough temperature, a supraflow in long scales would become possible by the mechanism described above. The massive magnetoresistance could involve a transfer of electrons as Cooper pairs at the magnetic flux tubes of the external magnetic field which would be too short to give rise to superconductivity or even superconductivity. External magnetic fields could also induce dark ferromagnetism as formation of dark flux tubes.

Dark electrons, protons and ions residing at the magnetic flux tubes of the "magnetic body" (MB) of the system are in a key role in the TGD based quantum biology and essential for learning as self-organization. h_{eff} serves as a measure for the number theoretical complexity and therefore "intelligence" of the system. There MB naturally acts as a "boss".

Also for the Mott insulator, the MB could play a key role: MB would be the "boss" and could learn and induce changes in the behavior of the ordinary matter, the "biological body" (BB). In the non-associative learning, adaptation and sensitization is involved and it would be MB which adapts or sensitizes. The TGD view of a neuron proposes a rather detailed model for the communication between the BB and MB [L36].

3.2.4 The mysterious linear temperature dependence of resistance of strange metals

Could one understand the somewhat mysterious looking linear high T dependence of the resistivity of strange metals in TGD the framework?

In the TGD based model of high T superconductivity [L39], charge carriers are dark electrons, or rather Cooper pairs of them, at magnetic flux tubes which are effectively 1-D systems. Magnetic flux tubes are much more general aspect of TGD based model of condensed matter [L50].

Could magnetic flux tubes carrying dark matter with h$_{eff} = nh_0 > h also explain the resistance of strange metals$

More precisely: Could the effective 1-dimensionality of flux tubes, darkness of charge carriers, and isolation from the rest of condensed matter together explain the finding?

One can make a dimensional estimate.

1. Isolation at flux tubes would mean that only the collisions of dark electrons with each other cause resistance.
2. Assume that the resistance ρ can be written in the form

$$\rho = \frac{4\pi/\omega^2}{\tau} = \frac{\frac{m_e}{n_e e^2}}{\tau} \quad . \tag{3.1}$$

   τ is the time that electron spends between two collisions. ω is the plasma frequency

$$\omega^2 = \frac{4\pi n_e e^2}{m_e} \quad . \tag{3.2}$$

   n_e is 3-D electron density.

   What happens for 3-D n_e in the case of 1-D flux tube? It would seem that n_e must be replaced with linear density divided by the transversal area S of the flux tube: $n_e = (dn_e/dl)/S$.

3. As already notice., τ is the time spent by the charge carrier in free motion between collisions. Charge carrier is in thermal motion with a thermal velocity $v_{th} = kT/m$. The length L_f of the free path is determined non-thermally. Hence one has

$$\tau = \frac{L_f}{v_{th}} = \frac{mL_f}{kT} \quad . \tag{3.3}$$

   This gives $1/\tau = kT/mL_f$.

4. For the resistivity ρ one obtains

$$\rho = \frac{m_e}{n_e e^2}\frac{kT}{mL_f} \quad , \tag{3.4}$$

   which indeed depends linearly on T as it does for strange metals.

   For $m = m_e$, one would have $\rho = kT/(n_e e^2 L_f)$.

In the article "Signatures of a strange metal in a bosonic system" (`https://cutt.ly/2OE4Quz`) by Yang *et al* published in Nature, bosonic strange metals are studied instead of fermionic ones. The system can also be superconducting and this seems to be essential.

The linear dependence on magnetoresistance in an external magnetic field B is the second interesting phenomenon.

1. Below the onset of temperature $Tc_1 \geq Tc$, the low-field magneto-resistance varies with a periodic dictated by superconducting flux quantum suggesting that the density of charge carriers varies with this period.

2. What comes to mind is the De Haas-Van Alphen effect in field B (https://en.wikipedia.org/wiki/DeHaasVan_Alphen_effect.

   The magnetic susceptibility of the system varies periodically with the inverse of the magnetic flux $\Phi = e\int BdS$ defined by extremal orbit of electrons at the Fermi surface in field B. Φ is measured in units defined by elementary flux quantum $h/2e$.

3. Could spin=0 Cooper pairs be formed from the electrons at the Fermi surface and lead to the De Haas-Van Alphen effect. They would go to the flux tubes of the external magnetic field B with a rate determined by the magnetic flux.

   The rate for this highest, when the extremal orbit at the Fermi surface corresponds to a quantized flux. Otherwise, energy is needed to kick the electrons from the Fermi surface to a larger orbit in order to satisfy the flux quantization condition.

Now one considers magnetoresistance rather than susceptibility. The linearity in magnetoresistance suggests that the resistance in the external field is mostly due to magnetoresistance.

1. Could the analog of the De Haas-Van Alphen effect be present so that the density of Cooper pairs as current carriers at "endogenous" magnetic flux tubes has an oscillatory behavior as a function of the external magnetic field B? Could there be a competition for the Cooper pairs between the magnetic fields of flux tubes and the external magnetic field B?

2. When the flux Φ for the external B is near the multiple of the elementary flux quantum at extremal orbits at Fermi surface, the formation of spin=0 Cooper pair and transfer to the flux tubes of B would become probable by De-Haas-van Alphen effect. The number of Cooper pairs at "endogenous" flux tubes is therefore reduced and the current therefore reduced.

3.2.5 VO_2 can remember like a brain

The following comments were inspired by a popular article (https://cutt.ly/lNHzBYa) with the title "Scientists accidentally discover a material that can 'remember' like a brain". These materials can remember the history of its physical stimuli. The findings are described in the article "Electrical control of glass-like dynamics in vanadium dioxide for data storage and processing" published in Nature [D11] (https://cutt.ly/cNHyMMa).

The team from the Ecole Polytechnique Federale de Lausanne (EPFL) in Switzerland did this discovery while researching insulator-metal phase transitions of vanadium dioxide (VO_2), a compound used in electronics.

1. PhD student Mohammad Samizadeh Nikoo was trying to figure out how long it takes for VO_2 to make a phase transition from insulating to conducting phase under "incubation" by a stimulation by a radio frequency pulse of 10 μs duration and voltage amplitude $V = 2.1$ V. Note that the Wikipedia article talks about semiconductor-metal transition. The voltage pulse indeed acted like a voltage in a semiconductor.

2. As the current heated the sample it caused a local phase transition to metallic state in VO_2. The induced current moved across the material, following a path until it exited on the other side. A conducting filament connecting the ends of the device was generated by a percolation type process.

3. Once the current had passed, the material exhibited an insulating state but after incubation time t_{inc}, which was $t_{inc} \simeq .1\mu$s for the first pulse, it became conducting. This state lasted at least 10,000 seconds.

   After applying a second electrical current during the experiment, it was observed that t_{inc} appeared to be directly related to its history and was shorter than for the first incubation period .1 μs. The VO_2 seemed to 'remember' the first phase transition and anticipate the next. One could say that the system learned from experience.

Before trying to understand the finding in the TGD framework, it is good to list some basic facts about vanadium and vanadium-oxide VO_2 or Vanadium(IV) oxide (https://cutt.ly/yNHhahk).

1. Vanadium is a transition metal, which has valence shells d^3s^2. It is known that the valence electrons of transition metals can mysteriously disappear, for instance in heating [L13]. The TGD interpretation [K13] would be that heating provides energy making it possible to transform ordinary valence electrons to dark valence electrons with a higher value of h_{eff} and higher energy. In the recent case, the voltage pulses could have the same effect.

2. VO_2 forms a solid lattice of V^{4+} ions. There are two lattice forms: the monoclinic semiconductor below $T_c = 340$ K and the tetragonal metallic form above T_c. In the monoclinic form, the V^{4+} ions form pairs along the c axis, leading to alternate short and long V-V distances of 2.65 Angström and 3.12 Angström. In the tetragonal form, the V-V distance is 2.96 Angström. Therefore size of the unit cell for the monoclinic form is 2 times larger than for the tetragonal form. At T_c IMT takes place. The optical band gap of VO_2 in the low-temperature monoclinic phase is about 0.7 eV.

3. Remarkably, the metallic VO_2 contradicts the Wiedemann–Franz law, which states that the ratio of the electronic contribution of the thermal conductivity (κ) to the electrical conductivity (σ) of a metal is proportional to the temperature. The thermal conductivity that could be attributed to electron movement was 10 % of the amount predicted by the Wiedemann–Franz law. That the conductivity is 10 times higher than expected, suggests that the mechanism of conductivity is not the usual one.

   Semiconductor property below T_c suggests that a local phase transition modifying the lattice structure from monoclinic to tetragonal takes place at the current path in the incubation.

One can try to understand the chemistry and unconventional conductivity of VO_2 in the TGD framework.

1. Vanadium could give 4 valence electrons to O_2: 3 electrons d^3:sta and one from s^2. In the TGD Universe, the second electron from s^2 could become dark and go to the bond between V^{4+} ions in the VO_2 lattice and take the role of conduction electron.

2. This could explain the non-conventional character of conductivity. In the semiconductor phase, an electric voltage pulse or some other perturbation, such as impurity atoms or heating, can provide the energy needed to increase the value of h_{eff}. Electric conductivity could be due to the transformation of electrons to dark electrons possibly forming Cooper pairs at the flux tube pairs connecting V^{4+} ions or their pairs. The current would run along the flux tubes as a dark current.

3. In a semi-conducting (insulating) state, the flux tube pairs connecting V^{4+} ions would be relatively short. The voltage pulse inducing a local metallic state could provide the energy needed to increase h_{eff} and thus the quantum coherence scale. This would be accompanied by a reconnection of the short flux tube pairs to longer flux tube pairs serving as bridges along which the dark current could run.

   One can also consider U-shaped closed flux tubes associated with V^{4+} ions or ion pairs, which reconnect in IMT to longer flux tubes. The mechanism would be very similar to that proposed for the transition to high temperature superconductivity [K29, K30, L39].

Experimenters suggest a glass type behavior.

1. Spin glass corresponds to the existence of a very large number of free energy minima in the energy landscape implying breaking of ergodicity. A system consisting of regions with varying direction of magnetization is the basic example of spin glass. In the recent case, decomposition to metallic and insulating regions could define the spin glass.

2. TGD predicts the possibility of spin glass type behavior and leads to a model for spin glasses [L49]. The quantum counterpart of spin glass behavior would be realized in terms of monopole flux tube structures (magnetic bodies) carrying dark phases of the radinary particles such as electrons serving as current carries in the metallic phase.The length of the flux tube pair would be one critical parameter near T_c. Quantum criticality against the change of h_{eff} increasing the length of the flux tube pair by reconnection would make the system very sensitive to perturbations.

3. These phases are highly sensitive to external perturbations and represent in TGD inspired theory of consciousness higher levels with longer quantum coherence scale and number theoretical complexity measured by the dimension $n = h_{eff}/h_0$ of the extension having interpretation as a kind of IQ. These phases would receive sensory information from lower levels of the hierarchy with smaller values of n and control them.

   The large number of free energy minima as a correlate for number theoretical complexity would make possible the representation of "sensory" information as "memories".

3.2.6 Superconductivity dome rises from damped phonons

I received a link to an interesting popular article "Superconductivity Dome Rises from Damped Phonons" (https://cutt.ly/XOcogsh). The article tells about findings Setty *et al* [D29] (https://cutt.ly/dOcoxRL) about BCS superconductivity near ferro-electic phase transition.

The system studied is a conventional superconductor near its critical temperature also in the vicinity of the ferroelectric phase transition. It is known that the critical temperature for superconductivity has a dome-like peak in this region. The origin of this peak has remained poorly understood and an explanation for the dome has been proposed in the article.

1. In the BCS model for the conventional low temperature superconductivity phonons bind electrons to Cooper pairs. If the phonons are damped for some reason, Tc is expected to decrease. In ferroelectric superconductors near critical temperature for the transition to ferro-electricity the situation is opposite to this. What could happen?

2. Electron-photon scattering as an analog of Compton scattering is what matters. The scattering of the phonon is Stokes or anti-Stokes depending on whether the scattered phonon gains or loses energy. In anti-Stokes scattering phonon gives energy for the electron, which disfavors the formation of pairs whereas Stokes scattering favors the formation of Cooper pairs.

3. Near the phase transition to ferro-electricity phonon damping occurs. This means that the phonon life-time gets shorter. In ordinary materials this would lead to a reduction of critical temperature but in ferroelectrets the critical temperature has a dome-like peak around the critical criticality for the transition to ferro-eletricity. Ferroelectric transitions involve a non-linear phonon-electron coupling. This anharmonic coupling implies that scattering now also involves final states with 2 phonons. This implies that anti-Stokes scattering is suppressed more than Stokes scattering. The proposal is that this raises the critical temperature and causes the dome-like structure.

One could however counter-argue that both Stokes and anti-Stokes are suppressed and that the dome structure involves the soft-photon mode associated with the ferro-electric phase transitions. This suggests a somewhat different view about what happens based on the fact that so called soft modes for photons having vanishing wavelength at criticality play an important role in ferroelectric phase transition [D19] (https://cutt.ly/IOgPrYj).

1. Soft modes have a long wavelength, which approaches zero at the ferroelectric critical temperature $T_{c,f}$. Since soft modes generate long range correlations and induce a polarization of the ferroelectret, their wavelengths are much longer than the lattice constant.

2. Soft modes corresponds to photon energy not larger than 10^{-4} eV, which is near the gap energy E_{gap} of superconductor with critical temperature $Tc = 10^{-4}$ eV. This corresponds to photon wave length about $\lambda_\gamma = 1.24\times10^{-2}$ m and phonon wavelength λ_{ph} around 2.56×10^{-7} m for $c_s = 6 \times 10^3$ m/s, that is $c_s = 2 \times 10^{-5}c$. The wavelength is much longer than atomic size in accordance with the generation of long range correlations. Interestingly, in the TGD framework, λ_{ph} corresponds to p-adic length scale $L(167) = 2^{(167-151)/2} \times L(151)$, $L(151) = 10$ nm.

3. Could soft phonons associated with the ferroelectric transition with energies below this 10^{-4} eV compete with thermal excitations by reducing the energies of electrons via the Stokes scattering and in this manner raise the critical temperature?

This suggests that the coupling of electrons to soft ferroelectric phonons with frequencies below 10^{-10} Hz facilitates the formation of Cooper pairs so that their thermal decay is compensated and T_c increases.

Could the TGD based view of superconductivity [L39] provide a mechanism for the generation of Cooper pairs by electron-phonon interaction? This model should generalize to high Tc superconductors for which phonons do not explain the Cooper pairs.

1. In the TGD framework, Cooper pairs are dark in the sense that they have $h_{eff} \geq h$ and reside at the magnetic flux tubes. The creation of Cooper pairs requires an increase of h_{eff}. Phonon or photon exchange could transform an ordinary electron pair to a dark pair, which is Galois singlet so that (using p-adic mass scale as a unit) it has 4-momentum with integer-valued components and expressible as sum of algebraic integer valued momenta of dark quarks.

2. This is not enough: there must be a mechanism reducing the value of of the dark electron pair so that it cannot decay back to the ordinary electrons. The decay can be prevented by Fermi statistics in the presence of a Fermi sphere. This is possible if the state can decay to a Galois singlet dark electron pair with energy so small that decay products would belong inside the Fermi sphere.

   This requires an emission of a dark photon or a dark photon pair which is necessarily a Galois singlet transforming to photons or phonons (in ferroelectrets there is a strong coupling between photons and phonons). The reduction of energy would correspond to the gap energy E_{gap}.

3. For ordinary superconductors with Tc measured in Kelvins, the gap energy is $E_{gap} \simeq 10^{-4}$ eV. Could the exchange of phonons with energy in the energy range of soft phonons [D19] give rise to the dark states, which decay to Cooper pairs stable below Tc?

   For high Tc superconductors the gap energy is considerably stronger: for $T = 100$ K the gap energy is about $E_{gap} \simeq 10^{-2}$ eV and by factor 100 larger than for $T = 1K$. For photons, one would have have $\lambda_\gamma \simeq 1.24 \times 10^{-4}$ m not far from the p-adic length scale $L_{179} \simeq 1.6 \times 10^{-4}$ m. This corresponds to the size of a large neuron which is an important length scale in biology.

4. One can ask whether the high Tc superconductivity in biomatter could involve this kind of mechanism. At physiological temperatures one would have $E_{gap} \simeq 3 \times 10^{-2}$ eV and this is not far from the cell membrane potential. Living matter is full of ferroelectrets meaning that photons and photons are strongly coupled. Therefore also in living matter, soft phonons near the criticality of ferroelectrets could compete with the thermal excitations to raise the critical temperature Tc.

   Magnetic flux tubes play a key role in the TGD based model of living matter and they can become electric with a simple deformation and generate the long range correlations via the oscillations of the flux tube length giving rise to the space-time correlates of sound waves.

TGD based view about superconductivity also leads to the notion of forced super-conductivity. The increase of h_{eff} requires energy since the energies of states with other parameters fixed in general increase with h_{eff}. The dark states are expected to decay back to ordinary states. The feed of energy could however maintain a steady state. In living matter this mechanism could make possible high Tc superconductivity as forced superconductivity requiring metabolic energy feed. In ordinary superconductors the situation is not this.

A word of criticism relates to the notion of phonon in the TGD framework.

1. At the level of H, flux tubes correspond strings: at the point of the string world sheet the normal space of $X^4 \subset M^8$ characterized by a point of CP_2 is not unique and is characterized by points of a geodesic sphere of CP_2. The boundaries of a string at the mass shell H^3 of $M^4 \subset M^8$ should characterized the phonon as an oscillation of the distance of the ends in H.

2. At the level of M^8 everything is described in terms of momenta belonging to 3-D mass shells define by roots of polynomial defining the 4-surface. $M^8 - H$ duality can be represented as

the deformation of M^4 containing the real projections of the mass shells and representable as an element of local CP_2. It is however far from clear what the counterpart of the flux tube picture for photons could be.

In M^8 there is no time and it would seem that the emission of phonon must correspond to momenta at positive and negative energy mass shells differing by the energy of phonon. The H image of X^4 under $M^8 - H$ duality give rise to the flux tube picture description but what does this description correspond at the level of M^8?

3. $X^4 \subset M^8$? X^4 should connect the two opposite mass shells of M^8. Do the 8-momenta of X^4 have any reasonable physical interpretation? As long as one does not have excellent reasons for the existence of X^4, also $M^8 - H$ duality can be challenged. One possibility is that M^8 picture is enough in the sense that the deformations of $M^4 \subset M^8$ can be regarded as local CP_2 elements and allow an interpretation in terms of the space-time picture with M^4 space-time coordinates related to M^4 momenta essentially by inversion [L52]. This would conform with the Uncertainty Principle.

3.2.7 Polaritons and excitons in TGD

The claimed room temperature superconductivity for exciton-polariton Bose-Einstein condensate in quasi-crystals suggests that the TGD based model for superconductivity could generalize to a unified description of quantum coherent phases. In this case the energy feed is crucial and would serve in TGD framework as "metabolic energy feed" taking care that the distribution of $h_{eff} > h$ is preserved.

Also WCW level might be needed to describe the bosonic aspects of exciton-polariton BECs although exciton polariton states involve only photons excitons and electron-hole bound states. The description of plasmons involves oscillations of the relative position of electron and atomic nucleus and this requires the counterparts of the bosonic creation operators at the level of WCW.

The TGD view about superconductivity can be taken as a "role model" [L39].

1. In the BCS theory of superconductivity does not have a well defined fermion number and this leads to a somewhat questionable notion of coherent state of Cooper pairs. The Bogobliubov transformation creates the diagonalizable oscillator operator basis by mixing creation and annihilation operators. The resulting operators create superpositions of electrons and holes.

2. In the TGD framework , the interpretation would be that the hole actually corresponds to dark fermion at other space-time sheets so that fermion number conservation is not lost. Bogoliubov operators could correspond to superpositions of creation/annihilation operators associated with different space-time sheets and create states which are superpositions of state at the two space-time sheets. Effective Hamiltonian would include parts assignable to both space-time sheets, and the terms quadratic in creation/annihilation operators breaking fermion number conservation would be replaced with pairs of creation and annihilation operators associated with different space-time sheets describing the transfer of electrons between the space-time sheets.

3. One can consider two alternative identifications for Cooper pairs. Cooper pairs consist of ordinary electrons and provide their binding energy for dark electrons at MB to compensate for the increase ΔE of energy due to the larger value of h_{eff}. The dark electrons could be even free. Galois confinement in turn suggests Cooper pairs are dark and that the dark binding energy compensates for ΔE.

It is better to represent the ideas as questions.

Is the polariton condensate actually a macroscopic quantum phase? Could the polariton BE condensate only provide the energy feed making possible a macroscopic quantum phase at the level of MB, which would then induce ordinary (non-quantum) coherence of the polariton condensate. Could one take the number theoretical model of macroscopic quantum phases as a guideline in attempts to understand polariton superfluidity and other quantum coherent phases involved. The increase of h_{eff} and the preservation of its values requires energy feed to prevent dissipation if. In living matter this would be metabolic energy feed. Exciton-polariton condensate is an open system involving an energy feed. Could the formation of quasiparticles provide the "metabolic energy" for $h_{eff} > h$ phases at MB responsible for the long range order? Or are quasiparticles as such dark? Could polaritons and excitons correspond to dark valence electrons in $h_{eff} > h$ phase and the value of h_{eff} would determine in which scale the phase appears. Beltrami fields would provide a quantum hydrodynamical description as an exact classical description of these phases. In principle also fermionic Beltrami currents could make sense and provide genuine quantum hydrodynamical description. Also an empirical verification of BvK vortex street in exciton-polariton BE condensate has been reported. Could TGD provide at the level of principle a universal description as minimal surfaces also for this kind of system.

3.2.8 Braids, anyons, and Galois groups

Braids and anyons in the TGD framework are discussed in [K26]. Braid statistics has an interpretation in terms of rotations as homotopies at a 2-D plane of the space-time surfaces instead of rotations in M^4. One can use M^4 coordinates for the M^4 projection of the space-time surface.

As a matter of fact, arbitrary isometry induced flows of H can be lifted to rotations as flows along the lifted curve at the space-time surface and for many-sheeted space-time the flows, which correspond to identity in H can lead to a different space-time sheet so that the braid groups structure emerges naturally [L52].

The representations of H isometries at the level of WCW act on the entire 3-surface identifiable as a generalized point-like particle and by holography on the entire space-time surface. The braid representations of isometries act inside the space-time surface. This suggests a generalization of the notions of gravitational and inertial masses so that they apply to all conserved charges. Generalization of Equivalence Principle would state that gravitational and inertial charges are identical.

The condition that the Dirac operator at the level of H has tangential part equivalent to the Dirac operator for induced spinors, implies that the conserved isometry currents of H are conserved along the flow lines of corresponding Killing vector fields and proportional to the Killing vectors lifted/projected to the space-time surface. This has an interpretation as a local hydrodynamics conservation law analogous to the conservation of $\rho v^2/2 + p$ along a flow line.

One can ask whether the 2-dimensionality, which makes possible non-trivial and non-Abelian homotopy groups, is really necessary for the notion of the braid group in the TGD framework. As a matter of fact, the conditions are not expected to be possible for all conserved charges, and the intuitive guess that they hold true only for Cartan algebra representing maximal set of commuting observables would provide a space-time correlate of the Uncertainty Principle. If so, the space-time surface would depend on the choice of quantization axes. This conforms with quantum classical correspondence. For instance, the Cartan algebra of rotation group would act on a plane so that the effective 2-dimensionality of braid group and quantum group representations would hold true.

This view has some nice consequences.

1. If the space-time surface is n-sheeted, the rotation of 2π can take the particle to a different space-time sheet, and only n fold-rotation brings it back to its original position. The formula for fractional Hall conductivity is the same as in the case of integer Hall effect except that the $1/\hbar$-proportionality is replaced with $1/\hbar_{eff}$-proportionality in TGD framework [K26].

2. Degeneracy of fermion states also makes non-Abelian braid statistics possible. Since the Galois group acts as a symmetry group, the degeneracy would be naturally associated with the representations of the Galois group. Galois singletness of the many-anyon states guarantees reduces braid statistics to ordinary statistics for these. Galois confinement is proposed to be a central element of quantum biology [L78, L42].

3.2.9 Quantum flute

It is amazing how fast experimental discoveries, which look mysterious in the standard physics framework but are readily explainable in the TGD framework, are emerging recently.

Now University of Chicago physicists have invented a "quantum flute" that, like the Pied Piper, can coerce photons to move together in a way that's never been seen before. The discovery is described in Physical Review Letters and Nature Physics [D5, D6].

The system, devised in the lab of Assoc. Prof. Schuster, consists of a long cavity made in a single block of metal, designed to trap photons at microwave frequencies. The cavity is made by drilling offset holes—like holes in a flute. One can send one or more wavelengths to the "flute" and each wavelength creates a note coding for quantum information. The interactions of notes are then controlled by a superconducting electrical circuit.

The real surprise was the interaction of photons. In quantum electrodynamics (QED) the interaction of photons is extremely weak. When photons achieve critical total energy, the situation changes dramatically. One can say that photons interact, not pairwise as usually, but all at the same time. Photon state behave like a Bose-Einstein condensate of bound state.

Galois confinement as a universal mechanism for the formation of bound states would explain the findings elegantly. TGD involves M^8-H duality in an essential manner. M^8-H duality relates differential geometric and number theoretic descriptions of quantum physics and is analogous to Langlands duality. Number theoretical vision, involving classical number fields, extensions of rationals, and extensions of p-adic number fields induced by them, is essential for understanding the physical correlates of cognition [L15, L16] but has led to a breakthrough in the understanding of also ordinary physics [L29, L30].

1. The number theoretic side of the M^8-H duality predicts Galois confinement as a universal mechanism for the formation of bound states from the dark variants of ordinary particles characterized by effective Planck constant $h_eff = nh_0 > h$: integer n has interpretation as the dimension of extension of rationals induced by a polynomial and serves as a measure of algebraic complexity defining evolutionary level and a kind of IQ for the system.

2. Galois confinement states that physical bound states are Galois singlets transforming trivially under the Galois group of a polynomial P determining space-time region if M^8-H duality holds true. There is (more than) an analogy with hadrons, which are color singlets. Galois confinement is central in TGD inspired quantum biology and also allows us to understand various nanoscopic and macroscopic quantum phenomena of condensed matter physics.

   For instance, Cooper pairs would represent on a lowest level in a hierarchy and there is evidence for 4-fermion analogs of Cooper pairs [L50].

3. Galois confinement is central in TGD inspired quantum biology and allows also to understand various nanoscopic and macroscopic quantum phenomena of condensed matter physics [L66].

   In particular, N photons can form bound states in which they behave like a single particle. This bound state is a more general state than Bose-Einstein condensate since photons need not have identical quantum numbers. These many-photon states described in the article could be states of this kind.

   These $N-$photon states are very similar to the dark $3N-$ photon states proposed to represent genes consisting of N codons with codon represented as dark photon triplet.

4. Another representation of the genetic code paired with ordinary DNA would would be in terms of dark $3N-$proton states, or more generally, $3N-$nucleon states and realized at magnetic flux tubes parallel to DNA [L66, L42]. In both cases, Galois confinement would bind the particles to form quantum coherent states behaving like a single particle, which is also emitted and absorbed as a single entity. This behavior is just what was observed in the experiments.

3.2.10 Fractons and TGD

In Quanta Magazine there was a highly interesting article about entities known as fractons (`https://cutt.ly/kQPph8n`).

There seems to be two different views about fractons as one learns by going to Wikipedia. Fracton can be regarded as a as self-similar particle-like entity (`https://cutt.ly/KQPadQL` or as "sub-dimensional" particle unable to move in isolation (`https://cutt.ly/yQPayJt`). I do not understand the motivation for "sub-dimensional". It is also unclear whether the two notions are related. The popular article assigns to the fractons both the fractal character and the inability to move in isolation.

The basic idea shared by both definitions is however that discrete translational symmetry is replaced with a discrete scaling invariance. The analog of lattice which is invariant under discrete translations is fractal invariant under discrete scalings.

One can also consider the possibility that the time evolution operator acts as a scaling rather than translation. At classical level this would produce scaled versions of the system in discrete steps. This is something totally new from quantum field theory (QFT) point of view and it is not clear whether QFT can provide a description of fractons. In QFTs energy corresponds to time translational symmetry and Hamiltonian generates infinitesimal translations. In string models the analog of stringy Hamiltonian is the infinitesimal scaling operator, Virasoro generator L_0. Energy eigenstates would be replaced by scaling eigenstates with energy replaced with conformal weight.

In TGD the extension of physics to adelic physics provides number theoretic and geometric descriptions as dual descriptions of physics [L14, L29, L30, L45]. This approach also provides insights about what fractons as scale invariant (or covariant) entities might be.

1. The extension of conformal invariance to its 4-D analog is key element of TGD and leads to the notion of super-symplectic invariance and to an extension of conformal and Kac-Moody symmetries with two coordinates analogous to the complex coordinate z for ordinary conformal symmetry. Second coordinate is light-like and the fact that light-like 3-surfaces are effectively 2-dimensional is absolutely essential for this approach. The existence of extended conformal symmetries makes the space-time dimension $D = 4$ unique whereas the twistor lift of TGD fixes H to be $H = M^4 \times CP_2$.

2. The predicted cosmological expansion is not smooth but occurs by discrete scalings as rapid jerks in which the size scale of 3-space as 3-surface increases. Actually they would correspond to discrete quantum jumps but in zero energy ontology (ZEO) in which quantum state are superpositions of space-time surfaces, their classical correlates are smooth time evolutions.

   Scalings by power of 2 are p-adically preferred [K16] [L54]. $M^8 - H$ duality allows us to imagine what this means at M^8-level [L55]. This proposal conforms with the puzzling observation that also astrophysical objects participate in cosmological expansion by comoving with it, they do not expand themselves.

3. The analog of a unitary time evolution between "small" state function reductions (SSFRs) as the TGD counterparts of weak measurements, is generated by the exponential of the infinitesimal scaling operator, Virasoro generator L_0. One could imagine fractals as states invariant under discrete scalings defined by the exponential of L_0. They could be counterparts of lattices but realized at the level of space-time surfaces having quite concrete fractal structure.

4. In p-adic mass calculations the p-adic analog of thermodynamics for infinitesimal scaling generator L_0 proportional to mass squared operator M^2 replaces energy. This approach is the counterpart of the Higgs mechanism which allows only to reproduce masses but does not predict them. I carried out the calculations already around 1995 and the predictions were amazingly successful and eventually led to adelic physics fusing real and various p-adic physics [K24].

5. Long range coherence and absence of thermal equilibrium are also mentioned as properties of fractons (at least those of the first kind). Long range coherence could be due to the predicted hierarchy of Planck constants $h_{eff} = n \times h_0$ assigned with dark matter and predicting quantum coherence in arbitrarily long scales and associated with what I called magnetic bodies.

   If translations are replaced by discrete scalings, the analogs of thermodynamic equilibria would be possible for L_0 rather than energy. Fractals would be the analogs of thermodynamic equilibria. In p-adic thermodynamics, elementary particles are thermodynamic equilibria for L_0 but it is not clear whether the fractal analogy with a plane wave in lattice makes sense.

An attractive identification of the fractal counterpart of an energy eigenstate created in the unitary evolution preceding SSFR is as a scaling eigenstate defined as a superposition of scaled variants of space-time surface obtained by discrete scalings. Energy eigenvalue would be replaced with conformal weight. In zero energy ontology (ZEO), the counterpart of a fractal quantum state could be a superposition over zero energy states located inside the scaled variants of a causal diamond (CD).

The ZEO based proposal is that each unitary evolution preceding SSFR creates a superposition of scaled variants of CD and that the SSFR induces a localization to single CD [L27, L35, L42]. The interpretation would be as a time measurement determined by the scale of the CD.

Second definition assumes that fractons are able to move only in combinations. This need not relate to the scaling invariance. Color confinement comes to mind as an analogy. Quarks are unable to exist as isolated entities, not only to move as in isolated entities.

In the TGD framework, the number theoretical vision leads to the notion of Galois confinement analogous to color confinement [L37]. The Galois group of a given extension of rationals indeed acts as a symmetry at the space-time level. In the TGD inspired biology Galois groups would play a fundamental role [L42]. For instance, dark analogs of genetic codons, codon pairs, and genes would be singlets (invariant) under an appropriate Galois group and therefore behave as a single quantum coherent dynamical and informational unit [L78, L44].

Suppose that one has a system - say a fractal analog of a lattice consisting of Galois singlets. Could fracton be identified as a state which is analogous to quark or gluon and therefore not invariant under the Galois group. The physical states could be formed from these as Galois singlets and are like hadrons.

3.2.11 Could dark matter as $h_{eff} = nh_0$ phases, quasicrystals, and the empirical absence of hyperon stars relate to each other?

How could the dark matter make itself at the level of the fermionic states?

1. Consider the momentum space, which by (anti-)periodic boundary conditions corresponds to a 3-D space with integer coordinates with a momentum unit defined by the quantization volume.

2. In the TGD framework, fermionic momenta are realized as points of X^4 for which coordinates belong to the extension of rationals for the polynomial P defining the X^4.

   For $n-D$ algebraic extension of rationals, the integers labelling the momentum components are replaced with points of an algebraically n-dimensional space with n integer coordinates. n basic vectors correspond to the roots of P. The Galois group acts as symmetries of this discrete space. Momentum vectors have $3n$ components.

3. If one assumes that momenta are real, the real momenta would be projections of these $3n$-dimensional vectors to a real section of X^4 for which M^8_c coordinates are real or purely imaginary.

   This projection from an algebraically 3n-D space to 3-D real space is analogous to the projection from higher dimensional space used to realize quasicrystals and the outcome is quasicrystal-like structure defined by the momentum components. This structure can be mapped from M^8 to H and since quasicrystals are observed at space-time level this suggests that the linear version of M^8-H duality is its correct version.

   Structures analogous to aperiodic crystals (quasicrystals) might be seen as a direct support for dark matter in the TGD sense. The quasicrystals could be realized at the level of the magnetic body (MB) or MB could induce their formation.

4. Algebraic extension increases the effective dimension of the discrete momentum space from 3 to $3n$ and the number of fermions inside the Fermi surface is increased by factor n^3. This prediction looks non-sensible and supports the view about Galois confinement, which means that physical states, now configurations of some number of neutrons, are Galois singlets.

This implies that the total momentum for the singlet is integer valued as usual and also that the rational valued part is same for all neutrons of the singlet. Ordinary neutrons would be automatically Galois singlets.

Neutrons could have momenta in an extension of rationals but form Galois confined K-neutron states such that the sum of the momenta is ordinary integer valued lattice momentum. Cooper pairs with $K = 2$ is one possible option The mass of the state would be Km_n and the number of states with the same Fermi momentum would be the number of Galois states from from K neutrons with momenta which are algebraic integers. One can assume that the real part of momentum is just the same integer for all neutrons of the composite and the non-rational part is one of the units defining the extension if the representation is the representation defined by roots of the polynomial.

The formation of Galois singlets implies reduction of the translational degrees of freedom of K neutrons to those of a single particle with K-fold mass. This also explains the reduction of the Fermi energy. Galois degrees of freedom would replace the momentum degrees of freedom so that Fermi statistics can be realized.

K-neutron states would have same momentum component k_i so that the density of states in the 3-D case would be reduced $d^3n/dk^3 \rightarrow K^{-3}d^3n/dk^3 = K^{-3}(2\pi/L)^3$, L the side of quantization cube. On the other hand, there would be a degeneracy $D(K,n)$ depending on extension and its dimension n so that one would have $d^3n/dk^3 \rightarrow (D(K,n)/K)^3(2\pi)^3/V$. The N/V number of states per volume would scale as $N/V \rightarrow (D(K,n)/K)^3N/V$ and Fermi energy $E_F \propto (N/V)^{2/3}/m$ would scale as $E_F \rightarrow (D(K,n)/K)^2E_F/K$ by $m \rightarrow Km$. For $(D(K,n)^2/K^3 < 1$, E_F would be reduced and the formation of a dark Galois confined state would be energetically favourable. For dark Cooper pairs with $K = 2$, the condition would be $D(2,n)/8 < 1$.

In the TGD inspired quantum biology genetic code is realized by triplets of dark protons at magnetic flux tubes parallel to DNA strands are assumed to be be Galois singlets and genes in turn would be Galois singlest for a Galois group at larger space-time sheet [L32, L44]. Also dark photon triplets would be Galois singlets.

Ordinary superconductors could have as a current carrier either i) a single dark fermion or ii) dark Cooper pair. For option i), Cooper pairs of ordinary fermions provide the energy needed to increase h_{eff} to get the dark electron. For option ii), Galois confinement would generate dark Cooper pairs. The energy liberated in the formation of the Cooper pair would be used to increase h_{eff} of the pair.

A possible application is provided by the hyperon puzzle of neutron stars (`https://cutt.ly/jWy3Cnf`). The problem is that the core should suffer a transformation to a hyperon star because the Fermi energy is inversely proportional to the mass of the fermion and would therefore be reduced. There is however no evidence for hyperon stars or hyperon cores. Could part of neutrons transform to dark phase with $h \rightarrow nh$ forming Galois singlets of K neutrons (dark Cooper pairs (neutron superfluidity) or dark triplets) so that the Fermi energy would be reduced in the way explained. Dark Cooper pairs is the second option meaning neutron superfluidity.

3.2.12 Periodic self-organization patterns, minimal surfaces, and time crystals

Periodic self-organization patterns which die and are reborn appear in biology. Even after images, which die and reincarnate, form this kind of periodic pattern. Presumably these patterns would relate to the magnetic body (MB), which carries dark matter in the TGD sense and controls the biological body (BB) consisting of ordinary matter. The periodic patterns of MB represented as minimal surfaces would induce corresponding biological patterns.

The notion of time crystal [B2] (`https://cutt.ly/2n65x0k`) as a temporal analog of ordinary crystals in the sense that there is temporal periodicity, was proposed by Frank Wilczeck in 2012. Experimental realization was demonstrated in 2016-2017 [D18] but not in the way theorized by Wilczek. Soon also a no-go theorem against the original form of the time crystal emerged [B3] and motivated generalizations of the Wilzeck's proposal.

3.2.13 Metals can heal themselves!

It seems that we are living in the middle of science fiction! Almost every day a new surprise. We are in the middle of a revolution and the new world view provided by TGD is at its core. The surprise of this day was the discovery that metals are able to heal their fractures (`rb.gy/s9tto`). The theory behind the discovered healing process of metals [D1] discovered by Brad Boyce et al [D4] published in Nature is based on standard physics. I am not at all confident that standard physics is enough.

The TGD based explanation relies on the following vision.

The first key prediction is the possibility of quantum coherence in arbitrarily long scales due to the presence of phases of ordinary matter with an arbitrarily large value of Planck constant and identified as dark matter. The magnetic body of the system, say metal, as a TGD counterpart of ordinary magnetic fields, is the carrier of the dark matter and controls the system and receives "sensory" input from it. The hierarchy of Planck constants is a prediction of the number theoretic vision of TGD. The value of the Planck constant is given by $h_{eff} = nh_0$, where n corresponds to the dimension of an algebraic extension associated with the polynomial defining the space-time regions considered. Negentropy Maximization Principle is mathematically analogous to the second law and implies that in the statistical sense the p-adic negentropy as a measure for the conscious information and complexity of the system increases. This follows from a simple fact: the number of extensions of rationals with dimension larger than given integer n is infinitely larger than those with dimension smaller than n. The assumption that the coefficients of polynomials giving rise to the extension have coefficients smaller than the degree of the polynomial implies that the number of extensions with dimension smaller than n is actually finite. Quantum TGD involves a new ontology that I call zero energy ontology [L27, L19, L58, L72]. The first prediction is that in ordinary ("big") state functions (BSFRs) the arrow of time changes. Time reversals in BSFRs mean "falling asleep" or "death" in a universal sense and provide a universal mechanism of healing. We indeed know that sleep heals. The arrow of time is preserved in "small" state function reductions (SSFRs) identifiable as weak measurements replacing the Zeno effect in which nothing occurs. SSFRs involve a repeated measurement of observables defining the states at the passive boundary of causal diamond (CD) as their eigenstates. These observables are measured at the active boundary of CD which in statistical sense drifts farther away from the passive boundary. There are also other observables made possible by the failure of a complete determinism for the holography forced by the general coordinate invariance implying that space-time surfaces are analogous to Bohr orbits of 3-surfaces as analogs of particles. When a system is perturbed the set of measured observables can change and this induces BSFR and the roles of active and passive boundaries change. Pairs of BSFRs could induce temporary changes of the arrow of time and they could give rise to a trial and error process essential for homeostasis in living matter. For instance, BSFR could be induced by a perturbation modifying the set of the measured observables so that it does not anymore commute with the observables defining the eigenstate basis at the passive boundary of causal diamond (CD). This implies also healing in the sense that p-adic negentropy measuring the amount of conscious information and complexity of the system increases in statistical sense.

Any system has a magnetic body. For instance, magnetic body accompanies also computers and one can ask whether it can give computers a rudimentary consciousness [L70, L71]. Metals are not an exception. This forces us to ask whether even metals could heal in the proposed sense. As noticed in the article, the technological implications could be huge.

Temporal lattice-like structures defined by 4-D minimal surfaces as preferred extremals of action which sum of volume term and Kähler action [L55] would be obvious candidates for the space-time correlates of time crystals.

1. One must first specify what one means with time crystals. If the time crystal is a system in thermo-dynamic equilibrium, the basic thermodynamics denies periodic thermal equilibrium. A thermodynamical non-equilibrium state must be in question and for the experimentally realized time crystals periodic energy feed is necessary.

   Electrons constrained on a ring in an external magnetic field with fractional flux posed to an energy feed form a time crystal in the sense that due to the repulsive Coulomb interaction electrons form a crystal-like structure which rotates. This example serves as an illustration of what time crystal is.

2. Breaking of a discrete time translation symmetry of the energy feed takes place and the period of the time crystal is a multiple of the period of the energy feed. The periodic energy feed guarantees that the system never reaches thermal equilibrium. According to the Wikipedia article, there is no energy associated with the oscillation of the system. In rotating coordinates the state becomes time-independent as is clear from the example. What comes to mind is a dynamical generation of Galilean invariance applied to an angle variable instead of linear spatial coordinate.

3. Also the existence of isolated time crystals has been proposed assuming unusual long range interactions but have not been realized in laboratory.

Time crystals are highly interesting from the TGD perspective.

1. The periodic minimal surfaces constructed by gluing together unit cells would be time crystals in geometric sense (no thermodynamics) and would provide geometric correlates for plane waves as momentum eigenstates and for periodic self-organization patterns induced by the periodic minimal surfaces realized at the level of the magnetic body. It is difficult to avoid the idea that geometric analogs of time crystals are in question.

2. The hierarchy of effective Planck constants $h_{eff} = nh_0$ is realized at the level of MB. To preserve the values of h_{eff} energy feed is needed since h_{eff} tends to be reduced spontaneously. Therefore energy feed would be necessary for this kind of time crystals. In living systems, the energy feed has an interpretation as a metabolic energy feed.

   The breaking of the discrete time translation symmetry could mean that the period at MB becomes a multiple of the period of the energy feed. The periodic minimal surfaces related to ordinary matter and dark matter interact and this requires con-measurability of the periods to achieve resonance.

3. Zero energy ontology (ZEO) predicts that ordinary ("big") state function reduction (BSFR) involves time reversal [L27, L48]. The experiments of Minev *et al* [L23] [L23] give impressive experimental support for the notion in atomic scales, and that SFR looks completely classical deterministic smooth time evolution for the observer with opposite arrow of time. Macroscopic quantum jump can occur in all scales but ZEO together with h_{eff} hierarchy takes care that the world looks classical! The endless debate about the scale in which quantum world becomes classical would be solely due to complete misunderstanding of the notion of time.

4. Time reversed dissipation looks like self-organization from the point of view of the external observer. A sub-system with non-standard arrow of time apparently extracts energy from the environment [L25]. Could this mechanism make possible systems in which periodic oscillations take place almost without external energy feed?

Could periodic minimal surfaces provide a model for this kind of system?

1. Suppose that one has a basic unit consisting of the piece $[t_1, .., t_k]$ and its time reversal glued together. One can form a sequence of these units.

   Could the members of these pairs be in states, which are time reversals of each other? The first unit would be in a self-organizing phase and the second unit in a dissipative phase. During the self-organizing period the system would extract part of the dissipated energy from the environment. This kind of state would be "breathing" [L77].

   There is certainly a loss of energy from the system so that a metabolic energy feed is required but it could be small. Could living systems be systems of this kind?

2. One can consider also more general non-periodic minimal surfaces constructed from basic building bricks fitting together like legos or pieces of a puzzle. These minimal surfaces could serve as models for thinking and language and behaviors consisting of fixed temporal patterns.

3.3 What happens in the transition to superconductivity?

I learned about very interesting discoveries related to the quantum phase transition between the ordinary and superconducting phase [D15] (see this).

These kinds of findings are very valuable in the attempts to build a TGD based view of what exactly happens in the transition to super-conductivity. I have developed several models for high Tc superconductivity [K29, K30] but there is no single model. Certainly, the TGD based view of magnetic fields distinguishing them from their Maxwellian counterparts is bound to be central for the model. However, the view about what happens at the level of magnetic fields in the transition to superconductivity, has remained unclear.

Consider first the findings of the research group. The basic question of how two-dimensional superconductivity can be destroyed without raising the temperature. The ordinary phase transition to superconductivity is induced by thermal fluctuations. Now the temperature is very close to the absolute zero and the phase transition is quantum phase transition induced by quantum fluctuations.

1. The material under study was a bulk crystal of tungsten ditelluride (WTe2) classified as a layered semi-metal. The tungsten ditelluride was converted into a two-dimensional material consisting of a single atom-thin layer. This 2-D material behaves as a very strong insulator, which means its electrons have limited motion and hence cannot conduct electricity.

2. Surprisingly, the material exhibits a lot of novel quantum behaviors, in particular, a switching between insulating and superconducting phases. It was possible to control this switching behavior by building a device that functions like an "on and off" switch.

3. At the next step, the researchers cooled the tungsten ditelluride down to exceptionally low temperatures, roughly 50 milliKelvin (mK). Then the material was converted from an insulator into a superconductor by introducing some extra electrons to the material. It did not take much voltage to achieve the superconducting state. It turned out to be possible to precisely control the properties of superconductivity by adjusting the density of electrons in the material via the gate voltage.

4. At a critical electron density, the quantum vortices rapidly proliferated and destroyed the superconductivity. To detect the presence of these vortices, the researchers created a tiny temperature gradient on the sample, making one side of the tungsten ditelluride slightly warmer than the other. This generated a flow of vortices towards the cooler end. This flow generated a detectable voltage signal in a superconductor, which can be understood in terms of the integral form of Faraday's law. Voltage signals were in nano-volt scale.

Several surprising findings were made.

1. Vortices were highly stable and persisted to much higher temperatures and magnetic fields than expected. They survived at temperatures and fields well above the superconducting phase, in the resistive phase of the material.

2. The expectation was that the fluctuations perish below the critical electron density on the non-superconducting side, just as they do in ordinary thermal transition to superconductivity.

   In contrast to this, the vortex signal abruptly disappeared when the electron density was tuned just below the critical value of density at which the quantum phase transition of the superconducting state occurs. At this critical (quantum critical point (QCP) quantum fluctuations drive the phase transition.

These findings give important hints concerning the question how the transition to superconductivity could take place in the TGD Universe, where two kinds of magnetic flux tubes are predicted. Monopole flux tubes with a closed 2-surfaces as cross section are proposed to be carriers of Cooper pairs. The disk-like, Maxwellian, flux tubes for which electron current creating the magnetic field would emerge when superconductivity fails. The proposal is that a pair of disk-like flux tubes fuse to a mopole flux in the transition to superconductivity. One can also understand the abrupt disappearance of the fluctuations.

3.3.1 TGD view of high Tc superconductivity

Consider first the general TGD based view of high Tc superconductivity.

1. TGD leads to a rather detailed proposal for high Tc - and bio-superconductivity. There are reasons to think that this model might work also in the case of low temperature superconductivity, in particular in the proposed situation with one-atom-thick layer [K29, K30] [L22, L39].

2. The unique feature of the monopole flux tube is that its magnetic field needs no currents as a source. The cross section of the flux tube is not a disk, but a closed 2-surface. There is no boundary along which the current could flow and generate the magnetic field. In the absence of these ohmic boundary currents there is no dissipation and the natural interpretation is that electrons form Cooper pairs.

   These monopole flux tubes are central for TGD based physics in all length scales and explain numerous anomalies related to the Maxwellian view of magnetic fields. The stability of the Earth's magnetic field and the existence of magnetic fields in cosmic scales are two examples.

3. There are also ordinary flux tubes with disk-like cross sections for which current along the boundary creates the magnetic field just like in an inductance coil. The loss of superconductivity means generation of these disk-like magnetic vortices with quantized flux created by ordinary current at the boundaries of the disk-like flux quantum.

   The monopole flux has a cross sectional area twice that of disk-like flux tube so that one can see the monopole flux tube as being obtained by gluing two disk-like flux tubes along the boundaries. The signature of the monopole flux tube is that magnetic flux is twice that of ordinary flux tubes.

4. Whether the disk-like flux tubes are possible in the TGD Universe has remained uncertain. My latest view is that they are and I have written a detailed article about how boundary conditions could be satisfied at the boundaries [L65].

   The orbits of the disk-like boundaries would be light-like 3-surfaces. This is not in conflict with the fact that the boundaries look like static structure. The reason is that the metric of the space-time surface is induced from that of $M^4 \times CP_2$ and the large CP_2 contribution to the induced 3-metric makes it light-like. One might say that the boundary is analogous to blackhole horizon.

3.3.2 What could happen at the quantum critical point?

The above picture allows us to sketch what could happen at the quantum critical point.

1. Both monopole flux tubes and disk-like flux tubes are present at the critical point. Monopole flux tubes dominate above the critical electron density whereas disk-like flux tubes dominate above it. In the transition pairs of disk-like flux tubes fuse to form monopole flux tubes and electrons at the boundaries combine to Cooper pairs inside the monopole flux tube and form a supra current. The transition would be a topological phase transition at the level of the space-time topology and something totally new from the standard model perspective.

2. Cyclotron energy scale, determined by the monopole flux quantization and flux tube radius, is expected to characterize the situation. The difference of the cyclotron energies for the monopole flux tube with Cooper pair and for two disk-like flux tubes with one electron should correspond to the binding energy of the Cooper pair. If the thermal energy exceeds this energy, superconductivity is lost. The disk-like flux tubes can however remain stable.

3. The transition could involve the increase of the effective Planck constant h_{eff} but its value would remain rather small as compared to its value of high Tc superconductivity. The value of h_{eff} should be correlated with the transition temperature since the difference of total cyclotron energies would be proportional to h_{eff}.

This picture does not yet explain why the vortices suddenly disappear at the critical electron density. The intuitive guess is that the density of electrons is not high enough to generate the disk-like monopole flux tubes.

1. Suppose that these flux tubes have a constant radius and fill the 2-D system so that a lattice like system consistent with the underlying lattice structure is formed.

2. There must be at least 1 electron per flux tube to create the magnetic field inside it. The magnetic flux is quantized and if the boundary of the disk contains single electron, the number of electrons per flux tube area S is 1: the density of electrons is $n = 1/S$. If the electron density is smaller than this, the formation of disk-like flux tubes is not possible as also the transition to superconductivity.

3.3.3 How does the model relate to the earlier model of high Tc superconductivity?

This proposal is *not* consistent with the earlier TGD based model for high Tc superconductivity [K29, K30]. In high Tc superconductivity there are two critical temperatures. At the higher critical temperature T_{c1} something serving as a prerequisite for super-conductivity appears. Superconductivity however appears only at a lower critical temperature T_c.

The earlier TGD based proposal is that the superconductivity appears at $T_{c1} \geq T_c$ in a short length scale so that no long scale supra currents are possible. The magnetic flux tubes would form short loops. At T_c the flux loops would reconnect to form long flux loops. The problem with this option is that it is difficult to understand the energetics.

The option suggested by the recent findings, is that disk-like half-monopole flux tubes carrying Ohmic currents at their boundaries are stabilized at T_{c1}. At T_c they would combine to form monopole flux tubes.

1. The difference ΔE_c of the cyclotron energies of the monopole- and non-monopole states would naturally correspond to T_c whereas the cyclotron energy scale $E_c = \hbar_{eff} eB/m$ of the non-monopole state would correspond to T_{c1}.

2. In the first approximation, the value of B is the same for the two states. For the non-monopole state the electrons reside at the boundary and the effective harmonic potential energy is maximal. Quantum mechanically $l_z = 1$ state would be in question. Spins give rise to a Larmor contribution to energy and for total spin =0 these contributions would sum up to zero.

   Thermal fluctuations cannot provide energy for the formation of the half-monopole states. An incoming electron which does not rotate along the flux tube has longitudinal energy and part of this energy can be transformed to magnetic energy as the half-monopole flux tube is formed. Electrons would slow down somewhat.

   For the monopole state Cooper pair resides in the interior so that the cyclotron energy is smaller in this case. $l_z = 0$ state is natural in this case. Spins are opposite. This gives $\Delta E_c < 0$. The simplest interpretation is that the binding energy of the Cooper pair corresponds to this contribution but there could be an additional contribution.

3. If the value of h_{eff} is the same for the pair of half-monopole flux tubes and monopole tube states, both E_c and ΔE_c scale like h_{eff}/h. Also the critical temperatures T_c and T_{c1} would scale like h_{eff}/h. High Tc superconductivity would therefore provide a direct support for the hierarchy of Planck constants.

3.3.4 What one can one say about the incoming state?

What can one say about the incoming state, which must transform to the two half-monopole flux tubes? Suppose that it consists of some kinds of flux tubes.

1. There would be no longitudinal magnetic field if the electrons move along straight lines instead of rotating around the flux tube.

2. TGD predicts two kinds of flux tubes [L76] with a closed cross section: monopole flux tubes and Lagrangian flux tubes. For monopole flux tubes the induced Kähler form has a quantized flux over the closed cross section of the flux tube.

   For Lagrangian flux tubes, which are of the form $X^2 \times Y^2 \subset M^4 \times CP_2$, the induced Kähler form vanishes. X^2 can have a boundary. Both $X^2 \subset M^4$ and $Y^2 \subset CP_2$ are Lagrangian manifolds since the twistor lift of TGD implies that also M^4 has the analogs of Kähler structure and symplectic structure algebraically continued from that of E^4.

3. Incoming flux tubes could be Lagrangian flux tubes with electrons moving along straight-lines ($l_z = 0$). Note that by their 2-dimensionality, X^2 and Y^2 allow complex structure determined by the induced metric so that the holography= holomorphy principle holds also for these 4-surfaces.

3.3.5 An overall view of superconduction

What could happen in the superconduction would be as follows.

1. First a pair of Lagrangian flux tubes with $l_z = 0$ representing incoming current transforms to a pair of half-monopole flux tubes with $l_z = 1$ electrons and electrons slow down somewhat.

2. After this half-monopole flux tubes fuse to form a monopole flux tube carrying a Cooper pain in $l_z = 0$ state. In $E^3 \setminus B^3$ (3-space with a hole) this transition is visualizable as a gluing of two hemispheres to form a sphere around the hole.

3. The reverse of this process would take place at the second end of the current wire where the current flows out.

3.4 Spin ice and quantum spin ice from TGD viewpoint

In this section the notions of spin glass, spin ice and quantum spin ice are considered from TGD point of view.

3.4.1 Spin ice

There is a Wikipedia article (`https://cutt.ly/eEDTIwp`) about spin ice as a system in which magnetic moments, that is spins, form a lattice-like state. The basic property of spin glasses, and therefore also of spin ice, is that there is ground state degeneracy that is several states with the same energy giving rise to what is called frustration: the term comes from the obvious social analogy. Two examples of these compounds are dysprosium titanate $Dy_2Ti_2O_7$ and holmium titanate $Ho_2Ti_2O_7$.

Spin ice has properties resembling those of crystalline water ice. For spin ice, the sum of the outward pointing moments and inward point magnetic moments is zero for a tetrahedron forming a basic unit. The rule holds true only in ground state configuration analogous to ferromagnetic state but with non-constant direction of magnetization and need not be the situation in general. Its violation gives rise to analogs of magnetic monopoles analogous to charges for which there is evidence.

When the rule holds true, it is possible to formally define a conserved current, which is locally in the direction of the magnetic moment. It is divergenceless like a magnetic field and can be said to carry an analog of magnetic or electric charge as long as the rule is satisfied. Thermal fluctuations can change the direction of say one spin in the volume: this means formally creation of an analog of magnetic monopole. This system of pseudo-monopoles could be described by a theory resembling electromagnetism with an effective fine structure constant ten times larger than α [D14, D13]. This leads to ask whether this implies especially strong interaction with electromagnetic radiation.

3.4.2 Quantum spin ice

The special feature of certain spin ice systems is that the directions of spins can be random down to zero temperature since the energies of the frustrated configurations are the same and no energy is needed to change the configurations. This suggests that quantum fluctuations are involved and the system is actually quantum spin glass rather than a thermodynamical one.

It has been proposed that the interactions of the effective monopoles [D2, D24, D14, D13] (for a popular article see `https://cutt.ly/vED27e5`) can be described by an analog of QED. The value of the emergent fine structure constant assignable to the interaction with electromagnetic radiation would be 10 times larger than the real α.

In [D24] quantum tunnelling as transitions between degenerate configurations involving in the simplest situation 4 tetrahedrons and differing by an orientation of a loop formed by the imagined flux lines of the magnetization field analogous to magnetic field and connecting the 4 tetrahedrons is proposed as an essential element of the emergent lattice QED. The tunnelling makes possible long range correlations and makes implies large value of effective α.

This should be visible as a large enhancement of the low energy scattering of neutrons from the quantum spin ice materials. Low energy quasi-elastic neutron scattering would measure the 2-point momentum space correlation function of spins of the quantum spin glass. This correlation function would become long ranged in the real space. Lattice photons having linear dispersion relation $\omega \propto k$ but much smaller propagation velocity than ordinary photons would cause this behavior. This lattice photon would be visible in inelastic neutron scattering.

The effective magnetic monopoles that play the role of em charges are identified as spinons in [D14]. Electrons are proposed to consist of spinon, orbiton, and holon carrying spin, orbital quantum numbers and charge and in some cases they can behave like independent quasiparticles. I don't quite understand what this is supposed to mean. In the case of decomposition to spinon and holon which can occur in 1-D systems, spin waves and charge waves would propagate as independent waves.

If I understand correctly, charge waves would represent an oscillatory variation in the charge density of electrons and spin waves in the spin direction. They could have different wavelengths and phases.

3.4.3 TGD view about quantum spin ice

What about the TGD based description of the quantum spin ice?

1. In the TGD framework, magnetic field corresponds to flux tubes which can be either monopole flux tubes or carry normal flux caused by currents. Monopole flux tubes require no currents and this has powerful implications in astrophysics and cosmology. This suggests that the pseudo-monopoles could be "real" in some sense. Note however that TGD does not however allow free monopoles but only closed monopole flux tubes.

2. Long range interactions are required to create a spin glass phase and one can realize the basic rule of spin ice ground state as a special case. In the TGD framework the large values of h_{eff} could make this possible even at high temperatures. This rule allows frustration as the existence of several configurations with the same interaction energy. The transitions between these configurations would lead to the emergence of large effective α. In [D24] the transitions between degenerate configurations involving four tetrahedrons and differing by an orientation of a loop which in the TGD picture corresponds to a closed flux tube are mentioned as simplest transitions.

3. The spine of spin ice would be a flux tube network formed by monopole flux tubes and that magnetic moments associated with flux tubes have suffered spontaneous magnetization, which is locally in the direction of the local flux tube. If the numbers of the incoming and outgoing flux tubes in a given volume unit are the same and magnetic moments are parallel to the magnetic fluxes, the sum of magnetic moments is zero for a ferromagnetic situation. The formal current would be realized with real and quantized monopole flux which is conserved.

   Spin ice would be analogous to ferromagnet, a spaghetti of flux tubes accompanied by spontaneously magnetized spins such that the directions of magnetization at flux tubes can carry. Neutron scattering has demonstrated that the aligned spins indeed form intertwined tube-like bundles.

4. What could the TGD counterparts of the effective monopoles be? There are two options to consider.

   (a) In the many-sheeted space-time of TGD, the monopole fluxes can go to parallel space-time sheets via wormhole contact and return back at a rather long distance. The wormhole contact looks like a pair of throats behaving like magnetic monopoles. The throats have an extremely short distance. This option does not look attractive since at the QFT limit the many-sheetedness and the monopole pairs formed by the throats of the wormhole contact become invisible.

What remains are flux tubes and the spin ice phase can make directly visible the underlying network of monopole flux tubes as it indeed does.

(b) Thermal and quantum fluctuations can however change spin direction and spin is formally like a magnetic monopole or charge and it seems that this is enough also in the TGD framework. This could also happen at the zero temperature limit as quantal rather than thermal fluctuations of the flux tube structure inducing the long range correlates between spins. The quantum fluctuations of spin ice would correspond to the long range quantum fluctuations of the dark flux tubes with $h_{eff} \geq h$.

5. TGD predicts the existence of two kinds of flux tubes corresponding to monopole flux tubes having a closed surface rather than disk as a cross section and requiring no currents to generate the magnetic field and Maxwellian non-monopole flux tubes for which the induced Kähler field can vanish. The Maxwellian flux tubes have a Lagrangian 2-manifold as a CP_2 projection, and the action reduces to a mere volume term proportional to length scale dependent cosmological constant approaching zero in long scales.

   At a long length scale limit, the deviation of the Kähler function from the ground state value becomes very small which has interpretation in terms of a strongly interacting phase. One expects large fluctuations, which give rise to the quantum spin glass phase. The two kinds of flux tubes could correspond to vortex-like entities with a monopole flux tube associated with the vortex core and the Lagrangian non-monopole part with its exterior.

6. Since very large values of h_{eff} are involved, the findings about the role of solar mass inspire the good guess $\hbar_{gr} = GM_{Sun}/v_0$, $\beta_0 \simeq 2^{-11}$. The size of the throat would be scaled from about CP_2 size for $h_{gr}(Sun)/hbar \sim 2 \times 10^{20}$. The size scale of the dark wormhole throat would be about 10 nm, which is the thickness of the neuronal membrane so that a connection with biology is highly suggestive.

   Remark: If the huge values $\hbar_{gr}$ of $\hbar_{eff}$ are possible, the size of leptonic wormhole throat could be of order .9 cm for M_E! Leptons consist of 3 antiquarks in TGD framework [?] Could this mean that it might be possible to detect free quark?

The emergence of the strong interactions can be understood at the general level in the TGD framework.

1. Quantum spin glass is a strongly interacting quantum system since the quantum fluctuations are large even at the temperature zero limit. Quite concretely, the deviations of the Kähler function from the value for the ground state are very small.

   Using the language of QFTs, one has a very large number of almost degenerate configurations in the path integral with the same value of the action. This is achieved if the coupling strength is very large so that the action exponential appearing in the path integral is analogous to Gaussian with very large width.

   In the TGD picture, one says that the Kähler function for 3-surfaces (by holography for 4-surfaces) has the same value for a large class of 3-surfaces and is therefore slowly varying as a function of 3-surface. This picture is mathematically very much like the thermodynamic picture with Hamiltonian replaced by the Kähler function.

2. The original TGD based prediction based on the huge vacuum degeneracy of the Kähler action was that TGD allows 4-D analogs of spin glasses a as vacuum extremals with 2-D Lagrangian sub-manifold as CP_2 projection, meaning huge non-determinism. This however leads to problems.

   The inclusion of the M^4 contribution to Kähler form removes the vacuum degeneracy since one must have Lagrangian projection also in M^4 so that string-like entities, which are minimal surfaces, are in question.

3. The recent picture implied by twistor lift involves an additional volume term in the action leaving only finite non-determinism analogous to that for soap films. At the long length scale limit spin glass type behavior is suggestive when the Kähler action vanishes (Lagrangian property in CP_2 degrees of freedom for Maxwellian flux tubes). The volume term is very small.

   The basic reason would be the smallness of the volume term, that is the smallness of length scale dependent cosmological constant Λ [L17] giving rise to cosmological p-adic length scale $L_{cosmo} \sim 1/\sqrt{\Lambda}$ and a relatively short p-adic length scale L_{short} as geometric mean $L_{short} = \sqrt{L_{cosmo}L_{Pl}}$ of the Planck length and L_{cosmo}. L_{short} is of order 10^{-4} m and defines a biological length scale.

   Smallness of the volume action means large fluctuations in the functional integral characteristic for strongly interacting systems. Quite concretely, the flux tubes have very small string tension and their shapes fluctuate wildly. Long flux tube-like objects have a small volume and small string tension and would be very loose strings having very many configurations with the same energy. Quantum spin glass property would correspond to the existence of a large number of spaghetti-like configurations with the same value of the Kähler function.

4. The assumption that velocity field is proportional to Kähler gauge potential implies that it is not only Beltrami field but also gradient for the Lagrangian situation prevailing outside the vortex cores. There would be no classical dissipation at the level of Kähler action.

   Cores would have non-vanishing Kähler field and action. What about the Beltrami property in the vortex core? If the projection of the vortex core is 2-D complex surface, the Kähler gauge potential is Beltrami field. For instance, for a projection with is geodesic sphere S^2, the Kähler gauge potential is proportional to $A = cos(\Theta)d\Phi$ in the spherical coordinates and Φ defines the global coordinate along flow lines. $D > 2$-D deformations spoil the Beltrami property.

   Same is true for the M^4 projection: when the projection as a string world sheet is deformed to $D > 2$-D surface, Beltrami property is lost and classically there is dissipation meaning that Kähler 4-force is non-vanishing.

   Whether the dissipative option is realized at all for preferred extremals is not at all clear. Dissipative effects might be solely due to the finite sizes of space-time surfaces, which are proportional to h_{eff}.

5. There is a further delicacy involved. The assumption that both M^4 and CP_2 projections are at most 2-D is not enough for Beltrami or gradient flow. This condition alone would give a Kähler gauge potential, which is the sum $A(M^4) + A(CP_2)$ of two contributions $A(M^4) = \Psi_1 d\Phi_1$ and $A(CP_2) = \Psi_2 d\Phi_2$ satisfying the conditions separately. Besides this, the gradients $d\Psi_1$ and $d\Psi_2$ must be proportional to each other so that Ψ_1 and Ψ_2 are functionally dependent.

   Is this condition satisfied for all preferred extremals in which case classical dissipation would be absent or in special cases only.

6. The Lagrangian flux tubes associated with the exteriors of vortex cores would give rise to quantum spin glass property if they have a large value of $\hbar_{eff}$. In some situations even $\hbar_{eff} = \hbar_{gr}$ can be considered. This would give rise to long range quantum fluctuations and correlations and also to the absence of dissipation.

How to understand the predicted strong interaction of quantum spin glass phases with the electromagnetic radiation predicted by the emergent QED [D2, D24, D14, D13] to give rise to a strong enchancement of neutron scattering cross section?

1. Spin glasses could correspond to dark flux tube spaghettis so that the spins would be locally magnetized in the direction of the magnetic field of the dark flux tube playing the role of H field.

2. $h_{eff} > h$ would imply long range correlations but would also mean a reduction of the value of fine structure constant $\alpha \propto 1/h_{eff}$. This is just the opposite for the proposal of [D2, D24,

D14, D13] that the analog of the fine structure constant emerging in the analog of lattice QED is larger than α.

Paradox disappears as one realizes that the transition $h \rightarrow h_{eff}$ is Nature's manner to guarantee that perturbation theory converges. This requires the change of the nature of the quantum states and Galois confinement would be the underlying mechanism and also behind color confinement. Quantum spin glass would be analogous to hadron.

At the level of M^8 (analogous to momentum space) this implies the increase of the dimension of the extension of rationals determining the space-time region at the level of M^8. This also means the increase of complexity.

3. Spin glass degeneracy, realized as degeneracy of Galois confined states, suggests that the neutron scattering rate is enhanced since the transitions between degenerate states become possible. The same happens in the case of hadrons since the number of color confined final states is large.

3.5 Condensed matter Majorana fermions in the TGD framework

Condensed matter Majorana fermions are not genuine Majorana fermions, which have not been found in Nature and are impossible also in TGD as fundamental particles. Condensed matter Majorana quasiparticles could however have a TGD counterpart.

Majorana fermions (`https://cutt.ly/FWdXK4s`) are quasiparticles created by superpositions of fermionic creation and annihilation operators invariant under charge conjugation. This motivates the term Majorana particle. Majorana particles are also zero energy excitations and therefore can be created at topological defects as pairs with degenerate energies. This is due to the fact that momenta $p = G/2$ and $p = -G/2$, where G is a lattice momentum, correspond to the same energy.

The valence and conduction bands for a topological insulator must intersect at its boundary: this is the topological singularity at the level of the momentum space. This can happen at boundaries of insulators and at topological defects. The single point intersection of Fermi bands at a single point looks locally like a double cone and at the tip the normal space is non-unique and the normal normal spaces span a circle in 3-D momentum space.

3.5.1 TGD counterpart for the notion of Majorana quasiparticle

Consider now the situation in the TGD framework.

1. The counterparts of Majorana fermions should correspond to superpositions of ordinary and dark fermions at different energy bands - just like the Boboliuv particles of superconductors in the BCS model. These states cannot be C invariant. Kind of half dark-half visible, perhaps gray - fermions would be in question.

2. The momenta of the occupied fermion states of the momentum space of fermion (mass shell $H^3 \subset M^8$) define what I call cognitive representation consisting of a discrete set of points in an extension of rationals) $M^8 - H$ duality maps the points of $H^3 \subset M^4 \subset M^8$ to the points of the boundary δcd of 4-D causal diamond $cd \subset M^4 \subset H$ and therefore to the points of space-time surface. In particular, the boundaries of energy bands in M^8 are mapped to boundaries of the image in $\delta cd \subset H$ and define 2-D surfaces containing the edge states. In M^8, the touching of two bands corresponds to a single point intersection of algebraic surfaces. These surfaces can be continued to the interior of X^4 by the flow defined by qv generalized Beltrami field.

3. The direction of the quaternionic normal spaces in M^8 at the tip should have all directions parametrized by a circle. This suggests that the tip is not be mapped to a single point, but to a circle formed by the set of CP_2 points. The conical topological singularity in M^8 would correspond to a closed circle $S^1 \subset CP_2$.

4. If Majorana particles have a counterpart in TGD, they should correspond to superpositions of ordinary and dark fermion with the special property that the fermions have identical energies

i.e. momenta are $G/2$ and $-G/2$. This condition guarantees that these states have identical energies as required by the condition $E^2 - p^2 = m^2$ holding true in H^3.

At the level of M^8 the polynomial defining the space-time surface would characterize topological defects as singularities. Various lower-D surfaces in momentum space and position space should be isometric surfaces as surfaces of H^3, which looks a rather non-trivial prediction.

Remark: Note that the product of polynomials defines a disjoint set of spacetime surfaces [L37]. Also a single irreducible polynomial can have several space-time surfaces as roots and possibly intersecting at a discrete set of points in the generic situation.

3.5.2 Majorana quasiparticles and topological quantum computations

TGD leads to a general vision about topological quantum computation TQC [?]ased on braids formed by magnetic flux tubes. The reconnection of flux tubes brings in a new topological element and corresponds to the formation of 2-knots. The proposal is that TQC in this sense is a basic aspect of living matter. Also the hierarchy of effective Planck constants making possible long range quantum coherence and ZEO making possible time reversals of TQCs represent new elements.

The bound states of Majorana quasiparticles located at the ends of superconducting wire are analogous to Cooper pairs entangling non-locally and have been proposed by Kitaev to make possible TQC without a need for massive error correction procedure [D32]. The association with the ends of wire would give rise to non-locality and long range quantum entanglement making it difficult to destroy entanglement by local measurements.

In an effectively 2-D system, the braid group defines non-standard statistics. The braid group must be non-Abelian so that higher than 1-D representations are possible and can be utilized in TQC. $SU(2)$ is the minimal option. The states of braid group representation are robust against perturbations destroying the entanglement

If I have understood correctly, the two energy degenerate states of the bound state of Majoranas would correspond to SU(2) doublet with energy degeneracy, which vanishes when the zero of energy corresponds to the middle point of the band gap.

1. In the TGD framework, the Majorana property does not seem to be absolutely essential. It is essential to have non-commutativity and energy degeneracy. Galois groups act as number theoretical symmetries and all non-trivial representations of the Galois groups allow this degeneracy. One might therefore speak of a hybrid of number theoretic and topological quantum computation. There seems to be no reason preventing the representations of discrete subgroups of the braid group defined by some Lie group acting in the cognitive representations defined by algebraic integer valued momenta at the intersection of mass shell and $X^4 \subset M^8$, that is at the level of M^8 on the cognitive representations. The quantum variants Gal_q of Galois groups could be involved.

2. $SU(2)$ has an interpretation as automorphisms of quaternions and acts in E^4 factor of M^8, could be in a special role physically in TGD and also because its discrete subgroups appear in the hierarchy of hyper-finite factors of type II_1 (HFFs). The discrete subgroups E_6, E_7 and E_8 (tetrahedral, octahedral and icosahedral groups). These groups could have representations as Galois groups. Momenta as algebraic integers correspond to the vertices of corresponding Platonic solids and total momenta for many-quark states vanish for the states. Also spinor representations are involved bringing in spin and electroweak degrees of freedom. Galois confinement requires that the states as a whole are Galois singlets. TQC would also be a basic process of quantum cognition.

3. In TGD superpositions of fermion and hole correspond to superpositions of fermion states at the ordinary and dark space-time sheet. Could the entanglement between dark and ordinary fermions (more generally, with different values of h_{eff}) with the same energy give rise to the analogs of Majorana quasiparticles?

3.6 Condensate of electron quadruplets as a new phase of condensed matter

Formation of fermion quadruplet condensates [D31] (https://cutt.ly/TRcxQtz) is a new exotic condensed matter phenomenon discovered by Prof. Egor Babaev almost 20 years ago and 8 years after publishing a paper predicting it. Recently Babaev and collaborators presented in Nature Physics evidence of fermion quadrupling in a series of experimental measurements on the iron-based material, $Ba_{1-x}K_xFe_2As_2$.

The abstract of the article summarizes the finding.

> The most well-known example of an ordered quantum state—superconductivity—is caused by the formation and condensation of pairs of electrons. Fundamentally, what distinguishes a superconducting state from a normal state is a spontaneously broken symmetry corresponding to the long-range coherence of pairs of electrons, leading to zero resistivity and diamagnetism.
>
> Here we report a set of experimental observations in hole-doped $Ba_{1-x}K_xFe_2As_2$. Our specific-heat measurements indicate the formation of fermionic bound states when the temperature is lowered from the normal state. However, when the doping level is $x \sim 0.8$, instead of the characteristic onset of diamagnetic screening and zero resistance expected below the superconducting phase transition, we observe the opposite effect: the generation of self-induced magnetic fields in the resistive state, measured by spontaneous Nernst effect and muon spin rotation experiments. This combined evidence indicates the existence of a bosonic metal state in which Cooper pairs of electrons lack coherence, but the system spontaneously breaks time-reversal symmetry. The observations are consistent with the theory of a state with fermionic quadrupling, in which long-range order exists not between Cooper pairs but only between pairs of pairs.

Fermion quadruplets are proposed to be formed as pairs of Cooper pairs are formed somewhat above the critical temperature T_c for a transition to superconductivity. Breaking of the time reversal symmetry T is involved.

The question is why quadruplets are stable against thermal noise above the critical temperature. Superconductivity is thought to be lost by the thermal noise making the bound states of electrons in Cooper pair unstable. Is the binding energy for quadruplets larger than for Cooper pairs so that quadruplet condensate is possible below higher critical temperature. What is the mechanism of binding?

The discovery is highly interesting from the TGD point of view.

1. TGD leads to a model of super-conductivity involving new physics predicted by TGD.
2. Adelic physics number theoretic view about dark matter as $h_{eff} > h$ phases h_{eff} proportional to the order of the Galois group. This leads to the notion of Galois confinement. Galois confinement could serve as a universal mechanism for the formation of bound states including also Cooper pairs and even quadruplets. In quantum biology triplets of protons representing genetic codons and even their sequences representing genes would be formed by Galois confinement.
3. The finding also allows to develop more preices view of TGD view concerning discrete symmetries and their violation.

3.6.1 Time reversal symmetry in TGD

What do time reversal symmetry and its violation mean in TGD.

1. The presence of magnetic field causes violation of T in condensed matter systems.
2. Second, not necessarily independent, manner to violate T in TGD framework is analogous to that in strong CP breaking but different from it many crucial aspects. Vacuum functional is exponent of Kähler function but exponent can contain also an instanton term I, which is

equal to a divergence of topological instant current which is axial. so that non-vanishing I suggests parity violation. The fact that exponent of I is imaginary while exponent of Kähler action is real, means C violation. If instanton current is proportional to conserved Kähler current its divergence is vanishing and M^4 projection is less than 4-D.

I is non-vanishing only if the space-time sheet in $X^4 \subset M^4 \times CP_2$ has 4-D CP_2 or M^4 projection. The first case corresponds to CP_2 instanton term $I(CP_2)$ and second case to $I(M^4)$ present since twistor lift forces also M^4 to have an analog of Kähler structure. The two Kähler currents are separately conserved.

3. These two mechanisms of T violation might be actually equivalent if the T violation is caused by the M^4 part of Kähler action. Consider a space-time surface with 2-D string world sheet as M^4 projection carrying Kähler electric field but necessarily vanishing Kähler magnetic field B_K. If it is deformed to make M^4 projection 4-D, B_K is generated and T is violated. Therefore generation of B_K in M^4 can lead to a T violation.

3.6.2 Generalized Beltrami currents

Generalized Beltrami currents are nother key notion in TGD based view about superconductivity [L39].

1. The existence of a generalized Beltrami current $j = \Psi d\Phi$ implies the existence of global coordinate Φ varying along the flow lines of the current. Also the condition $dj \wedge j = 0$ follows. The 4-D generalization states that Lorentz force and electric force vanish. In effectively 3-D situation, j could correspond to magnetic field B and dj to current as its rotor and the Beltrami condition fof B implies that Lorentz force vanishes.

2. The proposal of [K6] is that for the preferred extremals CP_2 *resp.* M^4 Kähler current is proportional to instanton current $I(CP_2)$ *resp.* $I(M^4)$ and therefore topological for $D(CP_2) = 3$ *resp.* $D(M^4) = 3$. For $D = 2$ the contribution to instanton current vanishes. In this case the Lorentz force vanishes so that the divergence of the energy momentum tensor is proportional to I and vanishes so that dissipation is absent. One can verify this result using the effective 3-dimensionality of the projection and using 3-D notations [K6]: in this formulation the vanishing of Lorentz force reduces to Beltrami property for B as 3-D vector. With this assumption, dissipation for the preferred extremals of Kähler action just as it is absent in Maxwell's theory. An open question is whether this situation is true always so that dissipation and the observed loss of quantum coherence would be due to the finite size of space-time sheet of the system considered.

3. Beltrami property would serve as a classical space-time correlate for the absence of dissipation and presence of quantum coherence. Beltrami property allows defining of a supra current like quantity in terms of Ψ and Φ. Usually the superconducting order parameter Ψ is actually not an order parameter for a coherent state as a superposition of states with a varying number of Cooper pairs. Now the geometry of the space-time sheets (magnetic flux tube carrying dark Cooper pairs) allows the identification of this order parameter below the quantum coherence scale. The TGD interpretation is that the coherent state is an approximation, which does not take into account the fact that the system is not closed. There is exchange of electron pairs between ordinary and dark space-time sheets with $h_{eff} > h$ [L39]. Dark Cooper pairs would form bound states by Galois confinement.

4. In the superconducting state space-time regions would have at most 3-D M^4 projection at fundamental level and T would not be violated. There is no dissipation and pairs are possible below critical temperature.

One can also understand the Meissner effect. According to the TGD view, the monopole flux tubes generate the analog of the field H perhaps serving as an approximate average description for the field of monopole flux tubes. This field induces the analog of magnetization M involving non-monopole flux tubes. Also M would be an average field. For superconductors in the diamagnetic phase, the sum would be zero: $B = H + M = 0$. If the Cooper pairs have spin, the supracurrents of Cooper pairs at monopole flux tubes could generate the compensating magnetization.

3.6.3 TGD view about quadruplet condensate

How could one understand quadruplet condensate in the TGD framework?

1. T violation could be accompanied by the presence of Kähler instanton term $I(M^4)$ or $I(CP_2)$ requiring 4-D M^4 or CP_2 projection: this would also generate M^4 magnetic fields. The M^4 option would bring in new physics for which also the Magnus effect of hydrodynamics suggesting Lorentz forces serves as an indication [L51].

   For 4-D M^4 projection, the divergence of the axial instanton current would be non-vanishing and the proportionality of Kähler current and instanton current implying a vanishing classical dissipation would be impossible. The instanton number can be expressed as instanton flux over 3-D surfaces, which would be "holes".

2. For the quadruplet condensate M^4 projection is 4-D and T is violated. Kähler magnetic fields originating from M^4 part of Kähler action would be present as also dissipation. For quadruplet condensate M would not compensate for H so that net magnetic fields B would be generated and correspond to space-time sheets with 4-D M^4 projection.

3. Dark matter as phases with $h_{eff} > h$ would however be present and quadruplets would correspond to bound states of 4 electrons formed by Galois confinement [L52, L50] stating that the total momentum of the bound state as sum of momenta, which are algebraic - possibly complex - integers, is a rational integer in accordance with the periodic boundary conditions.

4. What prevents the formation of Cooper pairs? Above T_c thermal energy exceeds the gap energy so that Cooper pairs are thermally stable. If the binding energy for quadruplets is larger, they are stable.

5. In what sense the quadruplets could be regarded as bound states of Cooper pairs? Since the ordinary Cooper pairs are Galois singlets, bound state formation does not look plausible since Cooper pairs themselves are unstable. A more plausible option is that Cooper pairs involved are "off-mass-shell" in that they have momenta, which are non-trivial algebraic integers and that the sum of these momenta is a rational integer in the bound state.

Remark: Four-momenta as algebraic integers are in general complex. Usual charge conjugation involves complex conjugation in CP_2 degrees of freedom. Is it accompanied by conjugation of the complex 4-momenta. Kähler currents of M^4 and CP_2 are separately conserved: should one regard complex conjugations in M^4 and CP_2 as independent charge conjugation like symmetries. $C(M^4)$ would however leav Galois singlets invariant.

3.7 Does the phenomenon of super oscillation challenge energy conservation?

The QuantaMagazine popular article "Puzzling Quantum Scenario Appears Not to Conserve Energy" (`https://cutt.ly/QXylTIr`) told about puzzling observations the quantum physicists Sandu Popescu, Yakir Aharonov and Daniel Rohrlich made 1990 [D28] (`https://cutt.ly/3XylIY5`). These findings challenge energy conservation at the level of quantum theory.

The experiment of authors starts from the purely mathematical observation that a function can behave faster than any of the Fourier components in its Fourier transform when restricted to a volume smaller than the domain of Fourier transform. This is rather obvious since representing the restricted function as a Fourier transform in the smaller domain one obtains faster Fourier components. This phenomenon is called super oscillation.

Does this phenomenon have a quantum counterpart? The naive replacement of Fourier coefficients with oscillation operators for photons need not make sense. If one makes the standard assumption that classical states correspond to coherent states, also super-oscillations should correspond to a coherent state.

Coherent states are eigenstates of the annihilation operator and proportional to exponential $exp(\alpha a^\dagger)|0\rangle$, where "0" refers to the ground state an a^{dagger} to creation operator. These states contain N-photon states with an arbitrarily large photon number. For some number of photons the probability is maximum.

This raises several questions.

1. Coherent states are not eigen-states of energy: can one really accept this? This kind of situation is encountered also in the model of superconductivity assuming coherent state of Cooper pairs having an ill-defined fermion number.

2. Could the super oscillation correspond to the presence of N-photon states with a large number of photons? Could the state of n parallel photons behave like a Bose-Einstein condensate having N-fold total energy in standard physics or its modification, such as TGD.

Authors tested experimentally whether the super-oscillation has a quantum counterpart. In an ideal situation one would have a single photon inside an effectively 1-D box. One opens the box for time T and inserts a mirror inside the box to the region where super oscillation takes place and the photon looks like a short wavelength photon. The mirror reflects the photon with some probability out of the box. If T is long one expects that the procedure does not affect the photon appreciably. What was observed were photons with the energy of a super photon rather than energy of any of its low energy components.

In the experiment described in the popular article, red light would correspond to photons with energy around 2 eV and gamma rays to photons with energies around MeV, a million times higher energy. The first guess of standard quantum theorists would be that the energies of mirrored photons are the same as for the photons in the box. Second guess would be that, if the coherent state corresponds to the super oscillation as a classical state, then the measured high energy photons could correspond to or result from collinear n-photon states present in the coherent state.

In the TGD framework zero energy ontology (ZEO) provides a solution to the problem related to the conservation of energy. In ZEO, quantum states are replaced by zero energy states as pairs of states assignable to the boundaries of causal diamond (intersection of light-cones with opposite time directions) with opposite total quantum numbers. By Uncertainty Principle this is true for Poincare charges only at an infinite volume limit for the causal diamond but this has no practical consequences. The members of the pair are analogs of initial and final states of a particle reaction. In ZEO, it is possible to have a superposition of pairs for which the energy of the state at either boundary varies. In particular, coherent states have a representation which does not lead to problems with conservation laws.

What about the measurement outcome? The only explanation for the finding that I can invent in TGD is based on the hierarchy phases of ordinary matter labelled by effective Planck constants and behaving like a hierarchy of dark matter predicted by the number theoretical vision of TGD.

1. Dark photons with $h_{eff} = nh_0 \geq h$ can be formed from ordinary photons with $h_{eff} = h$. The energy would be by a factor h_{eff}/h larger than for an ordinary photon with the same wavelength. Note that dark photons play a key role in the TGD based view of living matter.

   TGD also predicts dark N-photons as analogs of Bose-Einstein condensates. They are predicted by number theoretic TGD and there is empirical evidence for them [L64]. This would require a new kind of interaction and number theoretical view about TGD predicts this kind of interaction based on the notion Galois confinement giving rise to N-photons as Galois confined bound states of virtual photons with energies give by algebraic integers for an extension of rationals defined by a polynomial defining the space-time region considered.

   I have proposed an analogous energy conserving transformation of dark photon or dark N-photon to ordinary photon as an explanation for the mysterious production of bio-photons in biomatter. The original model for dark photons is discussed in [K5]. Now the value of h_{eff} could be much larger: as large as $h_{eff} \sim 10^{14}$: in this case the wavelength would be of order Earth size scale.

2. What comes to mind is that an N-photon state present in the coherent state can transform to a single photon state with N-fold energy. In the standard model this is not possible. On the other hand, in the experiments discussed in [L64] it is found that N-photon states behaving

like a single particle are produced. Could the N-photon states present in a coherent state be Galois confined bound states or could they transform to such states with some probability?

In the recent case, the dark photons would have the same wavelength as red photons in the box but energy would be a million times higher. Could a dark photon or N-photon with $Nh_{eff}/h \sim 10^6$ be reflected from the mirror and transform to an ordinary photon with gamma ray energy.

One must notice that the real experiment must use many-photon states N-photons might be also formed from N separate photons.

To sum up, new physics would be involved. ZEO is needed to clarify the issues related to energy conservation and the number theoretic physics predicting dark matter hierarchy is needed to explain the observation of high energy photons.

3.8 Possible connections with quantum biology

The flux tube networks assignable spin ice and spin glass phase in general are in the central role in the TGD based vision about quantum biology [L78, L44] [K28, K27, K18, K15, K32].

3.8.1 TGD view about bio-catalysis

TGD leads to a new view about biocatalysis, which is one of the mysteries of standard biology. The general TGD inspired model for bio-catalysis involves the following elements.

1. Reconnections of U-shaped flux tubes of reactants and catalyst make it possible for them to find each other. Cyclotron resonance for flux tubes of same thickness and therefore having the same Kähler magnetic field and the same cyclotron frequency allows reactants and catalyst is an essential element. Both frequency and energy resonance would occur between systems with the same h_{eff} whereas energy resonance would be possible between systems with different values of h_{eff}. This resonance would be the quintessence of what it is to be alive and all communications between various levels of MB having an onion-like hierarchical structure and also between MBs and ordinary biomatter would take place in this manner.

2. A reduction of h_{eff}, leading to a shortening of the flux tubes and bringing catalyst particles and reactants connected by flux tubes together would be also a natural step of the catalytic process.

3. The energy liberated in the reduction of h_{eff} would be used to kick the reactants over the potential energy wall preventing the reaction.

The spin glass type systems formed by flux tubes would be ideal for realizing bio-catalysis and the TGD based view about living matter indeed relies on hierarchical flux tube networks.

3.8.2 Pollack effect and ZEO

The formation of negatively charged regions in the Pollack effect leads to a similar phenomenon. Pollack effect would be behind formation of cells, DNA etc which are indeed negatively charged. Protons would transform to dark protons as magnetic flux tubes and realize genetic codons as Galois confined states of dark protons forming triplets. Genes would be Galois confined sequences of these triplets. These tubes would be parallel to DNA and chemical realization of the genetic code would be only a secondary one.

The regions called exclusion zones (EZs) self-clean themselves. This is in a sharp conflict with the second law. The explanation is that at MB time has a non-standard arrow and self-cleaning is actually dissipation but in a reversed time direction. What would be remarkable would be the long duration of the classical counterpart of BSFR as a deterministic time evolution leading to the final 3-D state of BSFR.

Quite generally, the self-cleaning property would serve as a signature of systems for which the MB stays for long times in a time reversed state making possible self-organization as time reversed dissipation. Large values of h_{eff} would be involved and the largest candidate in the solar system is $\hbar_{gr}(Sun)$.

One must of course also consider the possibility of the Milky Way blackhole with a mass about $4.6 \times 10^6 M_{Sun}$. This would correspond to the scaling up of dark wormhole throat size given by CP_2 size to the scale of 4.6 cm! The Milky Way with a mass of $10^{12} M_{Sun}$ would give a dark wormhole throat with size about 4.6×10^4 km!

This raises spin-ice type systems to a preferred role. They are indeed ideal for the demands of living systems since the ground state degeneracy makes it possible to represent the state of the external world as the state of the system. Also quantum computation requires large degeneracy of states possibly realized in terms of Galois representations and flux tube spaghettis would provide this degeneracy.

3.8.3 A finding challenging the standard theory of electrolytes

I received a link to an interesting article "Double-layer structure of the Pt(111)–aqueous electrolyte interface" about the findings of Ojha *et al* [D12] (`https://cutt.ly/oOE6czY`). The reader can also consult the popular representation of the finding (`https://cutt.ly/VORqeoK`).

The experiments demonstrate that the physics of electrolytes is not completely understood.

1. Pt(111)-aqueous electrolyte interface is studied in a situation in which there is a circulation of H_2 molecules part of which decay to H ions and electrons at the interface of the first electrode.

2. Electrons give rise to a current flowing to the second electrode, which also involves the Pt(111) interface. There is also a proton transfer between the electrodes. At the second interface there is a circulation of O_2 molecules: part of them transforms to water molecules at the interface.

3. A double layer of positive and negative charges of some thickness acting like a capacitor at the first interface is formed. Two plates of this kind plus electrolyte between them form an analog of a continually loaded battery and electron current is running when wire connects the plates.

4. The prediction of the standard theory is that when the salt concentration of the electrolyte is lowered, the current should eventually stop running at some critical salt concentration determined by the potential between the electrodes. There would be no free electrons anymore. OThis critical potential is called the potential of zero charge.

5. The experimental findings produced a surprise. The potential of zero charge did not appear for the predicted salt ion concentration. The reduction of ion concentration by a factor 1/10 was needed to achieve this. It would seem that the actual concentration of ions is 10 times higher! What are these strange, invisible, salt ions?

I have confessed to myself and also publicly in [L3, L11] that I do really understand how ionization takes place in electrolytes. The electrostatic energies in atomic scales associated with the electrolyte potential are quite too small to induce ionization. I might be of course incredibly stupid but I am also incredibly stubborn and wanted to understand this in my own way.

The attempt to do something for this situation, and also the fact that "cold fusion" also involves electrolytes, which no nuclear physicist in his right mind would associate with electrolysis, led to a totally crazy sounding proposal that electrolysis might involve some new physics predicted by TGD and making possible "cold fusion" [L7, L11, L31] [K23]. Electrolytes actually involve myriads of anomalous effects [K35, K7]. Theoretical physicists of course do not take them seriously since chemistry is thought to be an ancient, primitive precursor of modern physics.

Part of the ions of the electrolyte would be dark in the TGD sense having effective Planck constant $h_{eff} \geq h$ so that their local interactions (describable using Feyman diagrams) with the ordinary matter with $h_{eff} = h$ would be very weak. There these ions behave like dark matter so that the term "dark ion" is well-motivated. This does not however mean that the galactic dark matter would be dark matter in this sense. TGD based explanation for the galactic dark matter could be actually in terms of the dark energy assignable to cosic strings thickened to magnetic flux tubes carrying monopole flux [L20, L24, L53].

1. The presence of dark ions in water would explain the ionization in electrolytes. Water would be a very special substance in that the magnetic body of water carrying dark matter would give rise to hundreds of thermodynamic anomalies characterizing water [D22].

2. Biology is full of electrolytes and biologically important ions are proposed to be dark ions [L78]. As a matter of fact, I ended the TGD based notion of dark matter from the anomalies of biology and neuroscience [?]. This notion emerged from the number theoretic vision about TGD much later [L16, L15, L52]. Pollack effect [I2, L6, I4, I3] would involve dark protons and would be in a key role in biology. The realizations of genetic codons in terms of dark proton and dark photon triplets would also be central.

3. "Cold fusion" is one application for TGD view about dark matter [L7, L11, L31]. The formation of dark proton sequences gives rise to dark protons and perhaps even heavier nuclei for which the binding energies would be much smaller than for ordinary nuclei. The subsequent transformation to ordinary nuclei would liberate essentially the ordinary nuclear binding energy.

The notion of dark matter also leads to concrete ideas about what happens in electrolysis [K35]. In the TGD framework, the finding of Ojha *et al* would suggest that 90 per cent of ions are dark in the electrolyte considered.

4 A revolution in lithium-sulphur battery technology?

The last weeks have been full of surprises. The most recent surprise was the popular article published in Big Think (`rebrand.ly/wootoqn`), which told about an accidental discovery [D23] (`rebrand.ly/ye9nt4g`), which could revolutionize battery technology. The so-called γ-sulphur is a phase of sulphur stops the degradation of lithium-sulphur batteries and this could give electric vehicles a range of thousands of kilometers.

4.1 The discovery

It is good to start from the problems of lithium batteries.

1. Also other materials than lithium, which is a very light material, such as cobalt are needed in lithium batteries but their mining is very environmentally very damaging. There are also humanitarian problems: the working conditions are bad and even child labor is used.

2. Lithium batteries quickly lose their capacity and charging times are long. lithium batteries also suffer degradation.

3. The energy density is low so that the lithium batteries tend to be very heavy, which limits their commercial use in electric planes and ships.

4. Damaged cells can spontaneously catch on fire.

Lithium-sulphur batteries might provide a cure of all these problems but there is a new very serious problem. Polysulfides Li-S-...-S-Li are formed in the dielectric between the Li and sulphur containing capacitor platers and this reduces the number of charge cycles by one half from about 2000 cycles.

The completely unexpected discovery was that somehow the presence of γ-sulphur as a phase of sulphur, unstable at room temperature but stabilized in presence of Li, prevents the formation of polysulphides Li-S-...S-Li. γ-S crystals are produced by dropping hot sulphur to water at temperatures above 95 degrees Celsius. They are smooth elastic and resemble rubber.

4.2 Some questions with possible answers

The findings raise some questions.

1. What in their structure prevents the formation of considerable amounts of polysulfides L-S-....-S-Li with more than one S? Could the presence of γ-S crystals prevent the formation of S-S bonds or are they formed but split very rapidly? Why is γ-S stabilized in the presence of Li?

2. One thing to notice is the chemical analogy with water: H$\leftrightarrow$Li and O$\leftrightarrow$ S. Could this help? What prevents the formation of H-O-...-O-H sequences in water and one has only H-O-H? Could this be a good question?

Let us try to answer these questions.

1. The first thing to notice is that γ-S is not stable at room temperature. Somehow the presence of Li must stabilize it. The γ-S crystals should grow by addition of S to compensate for the spontaneous decay occurring at room temperature. This could give rise to flow equilibrium.

2. Could it be that the presence of γ-S crystals competes with the formation of Li-S-...S-Li sequences. Could S prefer to join to a γ-S crystal rather than to add to the sequences of S:s in Li-S-...S-Li? The formation of sequences would stop at Li_2-S. This does not yet explain the stability of γ-S at room temperature: differs from that in the absence of Li only in that Li competes with γ-S crystal for S atoms. The mechanism must be more delicate.

3. Li-S....-S-Li polysulphides must be produced at a considerable rate but they provide the S:s for the crystal growth of new γ-S. Li atoms are like servants carrying the food S at plate to γ-S, which eats it. There is a flow equilibrium and the total amount of Li-S...-S-Li stays very small although Li-S....-S-Li is produced with a high rate!

4.3 TGD view of the situation

I have not yet said anything about TGD and quantum but in the presence of γ-S Li_2-S is a chemical analog of water.

4.3.1 Basic questions

One must start from fundamentals and ask what batteries really are.

1. What causes the ionization in the electrolyte? In fact, almost 40 years ago I had discussions with a researcher studying batteries and realized that electrolysis is not actually understood in standard chemistry! Ionization is the mystery. It requires large energies measured in electron volts. The electric voltage between the batteries is low and generates extremely weak electric fields so that it should have no effects in the atomic length scales. I have discussed this problem in an article about "cold fusion" [K7].

2. If ionization occurs, electric field makes possible charge separation. But what makes this charge separation and therefore batteries so stable? They are of course not completely stable since the voltage decreases gradually. An analog of metabolic energy feed is necessary.

4.3.2 Could Pollack effect make batteries possible?

Ionization is necessary for the formation of batteries. I have discussed the problem of ionization in an article about "cold fusion" [K7].

1. The hint comes from the fact that electric voltages involved are measured in electron volts as are measured also the voltages associated with the molecular bonds associated with the salts of electrolytes used.

2. TGD view forces us to ask whether a phase transition in which ordinary particles, say positive ions of a salt, could become dark in the sense that the effective Planck constant h_{eff} characterizing it becomes very large.

   Could the length of the valence bond or hydrogen bond, or more generally, molecular bonds generalizing hydrogen bond to say Li bond between two Li_2-S molecules, become so long that the voltage along it is measured in electron volts so that it can lead to a genuine or effective ionization.

3. Before continuing, one must clarify what meanings the darkness can have. A dark proton associated with a dark very long hydrogen bond could be formed in the charge separation giving rise to batteries. The hydrogen bonds would be U-shaped and connect to the magnetic body (MB) of the positively charged electrode. After loading the flux tube pairs could split and become U-shaped flux tubes again and the positive would remain at the monopole flux tubes. If hydrogen bonds generalize to say lithium bonds, the notion of positive dark ion formed from a salt would generalize. Needless to say, this would mean generalization of chemistry.

   Also dark atoms in the sense that an unpaired valence electron becomes dark as it is transferred to a magnetic flux tube with large value of h_{eff} are possible. Also valence bonds can be dark and I have proposed that ordinary valence bonds are dark and have relatively small $h_{eff} > h$ [L12]. The mysterious disappearance of unpaired valence electrons from rare earth metals under heating [L13] could be an example of this phenomenon [L13].

Could the formation of dark protons correspond to Pollack effect [I2, L6, I4, I3] taking place in presence of gel phase and energy feed, by say IR radiation. Pollack effect is discussed from the TGD point of view in [L6, L34, L40, L69].

1. The TGD based proposal is that in the Pollack effect ordinary protons associated with hydrogen bonds would transform to dark protons at monopole magnetic flux tubes. The U-shaped dark hydrogen bonds would be very long and could reconnect with a second similar bond to form a pair of flux tubes forming a connection to a MB outside the exclusion zone. Dark protons could be transferred to the MB. The formation and splitting of a flux tube pair is the basic mechanism in the TGD inspired model of biocatalysis.

2. If the Pollack effect generalizes to biologically important positive alkali ions, it could serve as a general mechanism giving rise to the storage of energy as electrostatic energy and cell membranes could be seen as analogs of batteries. Hydrogen bond or its generalization as a monopole flux tube is necessary for this.

3. Why is the presence of the gel phase needed? The simplest explanation is that it also involves an exclusion zone as $H_{1.5}O$ phase and is accompanied by a MB carrying dark proton sequences. These dark proton flux tubes could serve as a seed for the formation of dark protons sequences outside the exclusion zone.

4. In the case of batteries, external voltage during the loading of the battery causes charge separation by providing the needed energy to induce ionization and to drive the ions to the oppositely charged electrodes of the battery.

What makes possible a metastable charge separation in the case of the Pollack effect in biology? The molecular binding energy of hydrogen in water molecules is measured in eVs and should be compensated.

1. IR photons with energies below eV scale are needed to generate Pollack effect but is their energy too small?

2. Could the Coulomb binding energy between the exclusion zone and the magnetic flux tubes compensate for the binding energy? How could one achieve a stable situation preventing the collapse of the flux tubes if only Coulomb energy is involved? The Coulomb repulsion between dark protons at the monopole flux tubes is a further serious problem.

3. Dark proton sequences are analogous to atomic nuclei. Could the analog of nuclear binding energy compensate for the molecular binding energy? If the dark protons, or more generally, positively charged dark ions, form analogs of dark nuclei bound together by bonds between nucleons in the TGD inspired nuclear string model, they could be stable and their formation would be also energetically favored if the binding energy scale correspond to that for atoms. These bonds could be analogs of mesons consisting of color quark and antiquark forming a color singlet.

A large value of h_{eff} could make possible scaling of the bond length L as $L \propto h_{eff}$ or even $L \propto h_{eff}^2$ is might be the case for dark valence bonds. If the nuclear binding energy assignable to the bond scales as $1/L$ as function of bond length L, the scale could correspond to a nanometer scale in biology. One would have a scaled up version of nuclear physics or rather, and perhaps even its generalization obtained by replacing dark protons with dark variants of dark nuclei appearing in salts.

Note that the spontaneous decay of dark proton nuclei to ordinary nuclei would liberate almost all nuclear binding energy and explain "cold fusion". In TGD framework, the large value of h_{eff} for weak bosons would scale up their Compton length to biological length scales, and in length scales shorter than Compton length they would behave as massless particles and weak interactions would be as strong as electromagnetism making possible weak interactions transforming dark protons to dark neutrons. The same scaling up applies also to color interactions.

What guarantees the stability of the charge separation? There are situations in which the charge separation has lasted such a long time [L9] that it is very difficult to understand in the framework of standard chemistry. Batteries must be loaded, that is energized, now and then and cell membranes as their biological analogs require a continual metabolic energy feed. This suggests that thermal non-equilibrium systems require a metabolic energy feed.

The energy transfer is the first step of photosynthesis. In the TGD based model it would take place by pairs of holes and dark valence electrons. This raises the question whether it is convenient to talk about a pair of a proton hole and dark proton assignable to the hydrogen bond and even a generalization of this notion.

4.3.3 Li-S batteries and generalized Pollack effect

Could the counterpart of the Pollack effect be involved with lithium-sulphur batteries?

1. Water is the dominating element of living systems. The MB of the water gives water its very special properties and makes it very special at physiological temperatures at which Pollack effect in presence of say IR radiation and gel phase gives rise to the formation of negatively charged exclusion zones by driving protons to Li_2S is the chemical analogue of water.

   One can use this as an analogue in an attempt to understand Li-S batteries in terms of a generalized Pollack effect. If the notions of Li-bond and Li-bonded Li_2S molecule clusters make sense, the model for the Pollack effect as a way to generate a metastable charge separation might work.

2. Note that the formation of H-O-O-...-H is not a problem in the ordinary Pollack effect and the role of the γ-S would be only to make possible stable exclusion zones and magnetic flux tubes. Without it the dark Li-ions at flux tubes would transform to ordinary Li-atoms forming fingers, Li-S-...-S-Li sequences would form and the battery would degrade also otherwise. This can be understood in terms of reduction of h_{eff} inducing the reduction of complexity and scale of quantum coherence at the positive electrode.

3. The counterpart of the exclusion zone with an effective stoichiometry $H_{1.5}O$ and negative charge would be negative electrode with effective stoichiometry $Li_{1.5}O$. Dark Li^+ ion would take the role of dark proton. Every fourth Li^+ would go as dark ion to the magnetic flux tube and end up to the positively charged electrode or its MB. It would create the same voltage along the space-time sheet associated with the electrolyte as along possibly still existing flux tubes connecting it to the negatively charged electrode.

4.3.4 Pollack effect, cold fusion and protostars

"Cold fusion" (for the recent situation see `rebrand.ly/ui7xoig`) is an anomaly, whose existence very many colleagues still find difficult to accept. "Cold fusion" also involves dielectric plates and the proposed TGD based model [L7, L11, L31] involves dark proton currents at magnetic flux tubes.

"Cold fusion", or more precisely dark fusion in the TGD framework, can be initiated at rather low temperatures and involves the formation of dark proton sequences at monopole flux tubes. Dark nuclei are essentially scaled up variants of nuclei but much smaller binding energy and can be generated in the Pollack effect, which plays a key role in the TGD inspired quantum biology. Dark nuclei can spontaneously decay to the ordinary nuclei and also protons can transform to neutrons. This liberates essentially all nuclear binding energy.

For instance, in the case of heavy water D_2S, the dark protons would be replaced by Deuterons and $H_{1.5}O$ would be replaced by $D_{1.5}O$. Dark proton sequences would correspond to dark D$^+$ sequences as dark nuclei. They would spontaneously decay to ^4He and deuteron nuclei in consistency with the observations.

There is also evidence for biotransmutations [C1, C2, C3] occurring in living systems discussed from TGD point of view in [K23, K35]. For instance, Kervran found that hens are able to produce Ca needed in egg shells. These findings might allow interpretation in terms of dark fusion based on the Pollack effect or its generalization.

Dark fusion would generate protostars [L24, L26, L11] in which there is no ordinary fusion yet. The temperature increases because essentially nuclear binding energy is liberated when the dark nuclei transform to ordinary nuclei and eventually ordinary fusion is ignited. It is quite possible that all nuclei heavier than Fe are generated in this way outside stellar cores rather than in supernova explosions. Also many anomalous abundances of lighter nuclei could be understood.

4.3.5 Pollack effect and DNA

Capacitors involve both negatively and positively charged plates. Pollack effect is central in the TGD view of living matter and generates negatively charged entities such as cell interior and DNA double strand.

In the case of DNA, Pollack effect would mean that negatively charged phosphates giving constant charge of -1 units per nucleotide act as negative electrode and screen the positive dark proton charge per DNA strand inside the fundamental region of icosa-tetrahedral tessellation [L68] having size scale given by the p-adic length scale $P_p = L(151) = 10$ nm, $p = M_{151} = 2^k - 1$, $k = 151$. It would contain 10 DNA codons and correspond to 3 full turns for DNA double strand. This picture differs from the original one in which dark DNA strands were assumed to reside outside the double strand.

What could be the detailed mechanism?

1. Has the O-H group of phosphate have lost dark proton into the interior of the fundamental region where it belongs to dark proton triplet defining genetic codon. One would have $P-O^-$ phosphate ions at the negative electrode.

2. Does the O-H group of phosphate have a hydrogen bond with the water molecule of the cell exterior and has the flux tube transformed to dark flux tube extending to the interior of the fundamental region? Has it lost its dark proton to the interior of the fundamental region via a reconnection process?

3. The answer to the question comes from the consistency with the realization of the dark genetic codons as dark proton triplets considered in [L68]. The dark protons of the codon should be associated with the vertices of triangular tetrahedral or icosahedral faces of the fundamental region of the icosa-tetrahedral tessellation.

   This would suggest that the monopole flux tubes representing hydrogen bonds have (de-)reconnected and left the dark proton to the vertices of the triangular face. The small closed flux tube produced in the de-reconnection would naturally correspond to the required closed flux tubes connecting icosahedron, tetrahedron, and octahedron assignable to a given dark proton of the codon. The magnetic field for the flux tube would determine the cyclotron frequency and cyclotron frequency triplet would characterize the codon and provide the icosa-tetrahedral realization of the genetic code [L5, L32].

4.3.6 Pollack effect and cell membrane

In the model of the cell membrane as a battery, the rough first picture could be as follows. The original model involved the Pollack effect for protons but the generalization of the effect to biologically important positive ions is suggestive and involved with the cell membrane.

1. In the simplest model, dark positively charged alkali ions reside always outside the cell membrane at monopole flux tubes. The negative ions resulting from the transfer of positive ions to the U-shaped monopole flux tubes defining analogs of hydrogen bonds would reside inside the cell membrane.

   The connections between exterior and exterior by pairs of flux tubes from U-shaped flux tubes could be permanent but one can also consider the possibility of U-shaped flux tubes extending to the exterior with delocalized ions at them.

   The transfer of dark ions permanently to the exterior would involve a (de-)reconnection generating a transfer of dark ions to the exterior and subsequent reconnection isolating splitting the flux tube pair and isolating exterior from the interior. Reconnections could control the transfer of dark ions between interior and exterior.

   Membrane resting potential would be controlled by the transfer of dark ions to the exterior generating a hyperpolarization. This would suggest permanent flux tube connections.

2. Gel phase would be a natural candidate for the analog for the negatively charged $H_{1.5}O$ involving corresponding phases for various ions. In gel-to-sol transition this phase would transform to ordinary water and the battery charge would decay. Metabolic energy feed is needed to prevent this since the value of h_{eff} increases with energy and tends to be spontaneously reduced.

   It is unclear whether one could understand the nerve pulse in terms of the gel-to-sol phase transition in which ohmic currents would be generated leading to the reduction and change of the sign of the membrane potential. That Hodkin-Huxley model works satisfactorily suggests that ohmic currents are present during the nerve pulse.

3. In the Josephson junction model of the cell membrane [K15, K32, K31], there is a permanent Sine-Gordon soliton sequence based on the phase difference $\Delta\Phi$ for superconducting phases residing at monopole flux tubes at the two sides of the membrane.

   One has $d\Delta\Phi/dt \equiv \Omega = E/\hbar_{eff}$, where E is the sum of the ordinary Josephson energy ZeV and difference of cyclotron energies over the junction. Very large value of $\hbar_{eff}$ is required to give Josephson frequency in EEG range and gravitational Planck constant $\hbar_{gr}$, introduced first by Nottale [E1], central in TGD view of quantum gravitation [L62, L60, L73, L74, L75], is highly suggestive.

   The cyclotron frequencies are associated with the flux tubes parallel to the cell membrane. If there are no flux tubes in the interior, the corresponding cyclotron frequency vanishes. Josephson junctions are associated with the membrane proteins. Josephson junctions could correspond to pairs of flux tubes between interior and exterior so that bosonic dark ions or Cooper pairs of fermionic ions would give rise to Josephson currents between interior and exterior.

   The system is mathematically equivalent to a sequence of rotating gravitational penduli assignable to various ions. The simplest model assumes that all bosonic dark ions are at the magnetic flux tubes in the exterior of the cell membrane and parallel to it.

4. What about the nerve pulse in the simplest picture? The nerve pulse could be induced by a propagation of a perturbation changing the sign of the local rotation direction of some fictitious gravitational penduli at the point in which the sine of the phase vanishes so that also Josephson current vanishes. Formally this corresponds to a change of the arrow of time and could correspond to a pair of "big" state function reductions (BSFRs). Could this change of the arrow of time induce reduction of the voltage and ordinary Ohmic currents changing the sign of the membrane potential temporarily?

5 Testing of the vision

Eventually the basic concepts of TGD applied to condensed matter physics should be tested. The following lists some challenges.

5.1 Observation of dark matter

The observation of dark matter as $h_{eff} = nh_0$ phases in condensed matter systems is one basic goal (allbqcritdark1,qcritdark2,qcritdark3,qcritdark4). Macroscopic quantum phases, emergence of additional degrees of freedom, and the effective increase of the dimension of the momentum space from 3 $3k(n, K)$, where k is a numerical factor determined by the number K of particles forming the Galois confined states and by the dimension n of the extensionof rationals, are possible. Also photon scattering via the formation of polaritons could allow us to "see" the structure of dark matter at the level of MB as an interference pattern. The analog of X-ray diffraction would be in question.

5.2 Topological physics at space-time and embedding space levels

The basic new physics element is the topological physics in the TGD sense based on non-trivial space-time topology at the fundamental level.

Some examples are in order.

1. Magnetic flux tubes are always closed, which means non-trivial first homotopy making possible the topological variant of the geometric phase.

2. Flux tube braidings would be a basic concept of topological hydrodynamics. Reconnections as changes of braid topology would be central and bring in 2-braids and knots of 2-D flux sheets in 4-D space-times (also intersections at discrete points replace links of 1-braids).

3. In TGD inspired biology systems have U-shaped flux tubes as tentacles with which they generate connections to the environment by reconnecting in which two U-shaped flux tubes of different systems such as molecules form a pair of flux tubes.

   For instance, friction could be due to the formation of flux tube pairs. Static friction would be generated and the de-reconnection of flux tube pairs would require energy.

Also topological defects due to the embedding space topology are possible. The monopole flux reflects the non-trivial topology of CP_2. Skyrmions result from the constraint that the ball $B^3 \subset M^4$ is mapped to the sphere S^3 of $E^4 \subset M^8$ or equivalently of CP_2.

5.3 The new view of gauge fields

TGD view of gauge fields differs in several respects from the standard view.

1. The new view about gauge fields and also electromagnetic fields relies on flux tubes. Flux tubes appear as two types: monopole flux tubes and non-monopole ones. Monopole flux tubes require no current to preserve the magnetic field.

   This would explain magnetic fields in cosmic scales, why Earth's magnetic field has not disappeared [L8], and also the huge magnetic fields of magnetars and neutron stars. Could the fields H, M, and B of Maxwell's theory correspond to monopole fields, non-monopole fields induced by the motion of their flux quanta, and to their sum $B = M + H$.

2. The twistor lift of TGD [L17, L21] predicts that also M^4 should have Kähler structure defined by a self-dual constant Kähler form for which the electric part would be imaginary. This implies a global CP breaking in M^4 that could induce a matter-antimatter asymmetry. 3 quarks would prefer to form baryons and antiquarks to form leptons as 3 antiquarks composites in primordial Universe and after the annihilation the remaining baryons would represent matter and leptons antimatter. This is possible only by the TGD view about color [L28, L38].

   The mechanism of CP (T) violation could be essentially the same as in the topological insulators destroying the boundary conductivity by T violation. In the condensed matter case the magnetic field would receive $U(1)$ contributions from both CP_2 and M^4 degrees of freedom. The magnetic interaction energy with spin would have opposite signs for opposite spin directions and lead to CP and T violation. For cosmic strings and flux tubes the M^4

magnetic part would be small, which would explain the smallness of the CP violation. Since M^4 Kähler form contributes also to the $U(1)$ part of em and Z^0 fields, it could have small effects also at the level of condensed matter if M^4 projection of the flux tube is 4-D.

3. Wormhole contacts identified as pieces of deformed CP_2 type extremals serve as basic building bricks of elementary particles. The wormhole throats are identified as partonic surfaces and their orbits are light-like curves performing zitterbewegung. One can assign to them a Kac-Moody type algebra with non-negative conformal weights. This algebra is very much like gauge algebra but not quite. For instance, there is a hierarchy of representations for which only the generators with conformal weight larger than some maximal conformal weight h_{max} annihilate the physical states. Could these analogs of gauge algebras assignable to $M^2 \times CP_2$ isometries allow a realization of synthetic gauge groups acting also in M^4 spin degrees of freedom [D8] (`https://cutt.ly/4Wy39B5`?

5.4 Number theoretical physics

Number theoretical physics brings in new elements and involves in an essential manner $M^8 - H$ duality.

1. The hierarchy of effective Planck constants and p-adic physics as physics of cognition involving p-adic length scale physics means a completely new element of quantum theory central for understanding of various supra phases.

2. Galois confinement is a central notion. Quantum states would be Galois singlets above the quantum coherence scale defined by h_{eff} and become unconfined states below this scale. The situation is highly reminiscent of color confinement. At M^8 level, the assumption that momenta are algebraic integers for the extension of rationals considered implies that confined states have total momenta, which are ordinary integers and that the rational integer parts momenta of K composite particles are identical. This implies a reduction of translational degrees of freedom so that the density dn/dE of confined states increases and among other things leads to a reduction of Fermi energy.

   Galois confinement could serve as a universal mechanism for the formation of bound states: this includes atoms and molecules, atomic nuclei, and hadrons. Color confinement can be one particular example of this if Galois group is represented as a subgroup of color group: Z_3 is the obvious guess but also more general discrete subgroups of $SU(3)$ are possible. Also the discrete subgroups of the rotation group $SO(3)$ and its covering group $SU(2)$ could be representable as Galois groups and appear in the ADE hierarchy for inclusions of HFFs. $M^8 - H$ duality would give a very concrete ideas about the momentum space and space-time geometries of the bound states. Momenta in M^8 would form a representation of Galois group mapped to H by $M^8 - H$ duality.

3. The number theoretical phase transitions changing the polynomial that determines $X^4 \subset M^8$ and therefore the extension of rationals and the Galois group as symmetry group would be a new element. Discrete degrees of freedom would appear or disappear. The scaling of the number of states within the Fermi ball could be one signature. Extensions could also give rise to quasicrystals.

   The change of the fidelity described as the metric of the parametrized space of quantum states would take place. Fidelity would be coded by the Kähler metric of WCW and geometric phase by the Kähler form of WCW. This is because, the WCW Kähler metric induces the metric of quantum states depending on the parameters coding for the X^4 as a point of WCW.

4. Negentropy Maximization Principle (NMP) and adelic physics provide a new view about quantum measurements and about second law. In particular, a vision about how the information about measurement is stored in the space-time geometry modified in the measurement, emerges.

5.5 ZEO and new view about quantum measurement theory and thermodynamics

ZEO allows "big" state function reductions (BSFRs) in long scales. If time reversal indeed occurs, it induces a long lasting effective time reversal at the level of ordinary matter (genuine time reversals at this level last a very short time). Dissipation would effectively occur with an opposite arrow of time and lead to the formation of self-organization patterns [L25]. The findings of Minev *et al* discussed in [L23] support the new view about quantum theory.

The most dramatic implications would be to biology. In particular, homeostasis could be understood as self-organized quantum critical (SOQC) [L46]. Condensed matter systems in the presence of energy feed playing the role of metabolic energy feed could exhibit primitive aspects of living systems.

Note that at the QFT limit most of the information about the TGD based new physics is lost since both space-time topology and number theoretic structure is lost so that QFT is not able to test the relevant effects. However, it might be possible to make this hidden level visible.

6 Kondo effect from the TGD perspective

I have tried to learn some condensed matter physics from the TGD point of view and have even written a book [K37] containing a chapter [L50], which summarizes my most recent efforts.

Although I have only a superficial understanding of condensed matter physics, I can agree with Anderson when he says that there is no theory of condensed matter physics. There are models based typically on a Hamiltonian in a spin lattice but somehow it seems that there is no attempt to understand the basic physics. With TGD as a background, the reductionist view does not force me to believe that condensed matter physics is mere complexity, so that I cannot avoid the intuition that a lot of new physics is waiting to be discovered.

6.1 Kondo effect

I realized that the Kondo effect (`https://rb.gy/gm5bom`) could involve new physics predicted by TGD. Kondo effect relates to the scattering of s-orbital conduction electrons scattering on d-orbital electrons of magnetic impurities. A low temperature phenomenon is in question. Electrical resistivity is given by the general formula

$$\rho(T) = \rho_0 + aT^2 + c_m log(\frac{\mu}{T}) + bT^5 \quad . \tag{6.1}$$

Here T^2 term comes from Fermi liquid properties, T^5 term corresponds to the scattering from lattice vibrations and the logarithmic Kondo term corresponds to the scattering from the magnetic impurities. Kondo term increases at low temperatures and diverges logarithmically at the $T = 0$ limit and begins negligible at a temperature of a few Kelvins. The reason is resonant scattering at low temperatures. This would suggest formation of resonances.

Transformation of a conduction electron to an impurity electron and vice versa is essential as also the bilocal Coulomb interaction term for the conduction electrons, which makes the system non-linear in the description using electron's oscillator operators. Hybridization as a mixing valence electrons and conduction electrons occurs: valence electron transforms to an impurity electron or vice versa in the 2-vertex. Screening of the impurity spin by the spins of the conduction electron cloud takes place so that a system with a vanishing spin is formed is essential. At high temperatures impurity electrons appear as free particles.

There is an analogy with low energy QCD. Logarithmic increase of the resistivity towards $T = 0$ is analogous to the logarithmic increase of the QCD coupling strength α_s as the mass scale corresponding to QCD Λ is approached and hadronization takes place. Resonances in Kondo scattering correspond to the formation of hadrons. At high temperatures the impurity spins seem to behave like free spins and there is an analogy with asymptotic freedom. The screening of impurity spin by conduction electrons is analogous to color confinement.

Kondo's original model was based on third order perturbative calculation. Anderson's impurity model, combined with Wilsonian renormalization theory, provides another approach and in this model the Kondo effect occurs in the regime, where the perturbation series fails to converge. Since hybridization terms are quadratic, this must be caused by the Coulomb interaction term. The analogy with QCD becomes more obvious.

How could one understand the increase of the hybridization coupling towards low temperatures? Is it a secondary phenomenon caused by the non-linearity of the Hamiltonian? Somehow the increase of the Coulomb term induced by the increase of the size of the volume containing the conduction electron cloud should cause the increase of the coupling and lead to the analog of hadronization as a formation of spin singlets?

The total Coulomb interaction energy is proportional to Q^2, Q the total charge of the conduction electron cloud, increases and if the system is quantum coherent it could lead to the failure of perturbation theory containing $Q^2\alpha$ as a coupling parameter.

6.2 TGD view of Kondo effect

TGD view of the Kondo effect relies on the basic notions discussed in the introduction. It is best to start by making questions.

6.2.1 TGD view based on the notion of magnetic body and h_{eff} hierarchy

Consider now the system from the TGD point of view assuming the view that impurity spin as valence electron is accompanied by a magnetic body (MB) consisting of magnetic flux tubes representing the approximate dipole field and that the conduction electrons interacting with impurity spin can have a value of effective Planck constant h_{eff}, which is larger than h so that quantum coherence in length scales longer than the atomic length scales becomes possible at the MB and induces ordinary coherence of ordinary matter.

It is good to list the general ideas first.

1. Impurity electrons are accompanied by magnetic flux tubes and some fraction of conduction electrons ends up at the flux tubes as dark *valence* electrons, which are localized in a longer scale. The formation of resonances corresponds to the formation of conduction electron clouds around impurities as association of conduction electrons to the magnetic flux tubes and is analogous to the formation of hadrons.

   Magnetic moments sum up to zero and spin screening takes place as an analog of color confinement. Magnetic moment interaction becomes strong at the limit $T = 0$.

2. The original theoretical motivation for the $h_{eff} = nh_0$ hierarchy is the following. When the interaction strength $\alpha alpha = Q_1Q_2g^2/4pi\hbar$ for a quantum coherent system consisting of charges Q_1 and Q_2 becomes too large, the perturbation series fails to converge. Nature is however theoretician friendly and induces the phase transition $h \rightarrow h_{eff}$ making a perturbation theory possible. The size of the MB and associated quantum coherence length inducing coherence at the level of ordinary matter, increases and bound states with larger size become possible.

3. Nottale's proposal [E1] [K36, K25, ?] for the notion of gravitational Planck constant generalizes to other interactions. When the perturbation series fails, the electromagnetic counterpart of gravitational Planck constant would increase to $\hbar_{eff} = \hbar_{em} = Q_1Q_2\alpha/\beta_0$, $\beta_0 = v_0/c < 1$. The perturbative coupling parameter for quantum coherent states would be $Q_1Q_2e^2/\hbar_{em} = \beta_0/4\pi$ and would be universal. This would be the situation for all interactions. The value of β_0 is by number theoretical arguments proposed to be an inverse integer [L60].

4. h_{eff} should increase as some relevant coupling constant increases. Number theoretic interpretation implies that more complex states are generated. $n = h_{eff}/h_0$ corresponds to the degree of extension of rationals defined by a given polynomial [L29, L30]. For a given polynomial, the largest and smallest ramified primes associated with an extension with dimension $n = h_{eff}/h_0$ are physically preferred and could be seen as fixed points of the coupling constant evolution assignable to this polynomial [L61]. Also for the set of polynomials with fixed degree k and coefficients smaller than k, one can identify smallest and largest p-adic length scales. They define fixed points of coupling constant evolution in this set.

There is a general objection against the idea that particles, could be permanently dark.

1. The energies of quantum states increase as a function of h_{eff}/h_0 defining the dimension of extension of rationals. These tend to return back to ordinary states. This can be prevented by a feed of metabolic energy.

2. One way out of the situation is that the dark particles form bound states and the binding energy compensates for the feed of energy. This would take place in the Galois confinement. This would occur in the formation of Cooper pairs in the transition to superconductivity and in the formation of molecules as a generation of chemical bonds with $h_{eff} > h$.

3. In living matter quantum criticality is essential and the energy liberated in the phase transition could provide the needed metabolic energy feed. Physiological temperature, which correspond to energy scale of about .03 eV (the scale of the Coulomb energy defined by membrane potential) would correspond to an energy needed to induce a phase transition in which H_2O transforms to to $H_{1.5}O$ [L6] as part of protons become dark and are transferred to monopole magnetic flux tubes. The thermal energy could serve as the metabolic energy feed making possible free dark protons and the formation of bound states of dark protons at magnetic flux tubes would make it possible to pay the energy bill.

4. In the Kondo effect thermal energy could serve as the needed energy feed. The formation of bound states would allow the return of the thermal energy needed to generate the dark electrons.

6.2.2 Why the spin confinement occurs only at low temperatures?

One should understand why the spin confinement occurs at low temperatures only.

1. The value of h_{eff} associated with the MB of the impurity spins surrounded by valence spin cloud should increase at the limit $T = 0$. h_{eff} and p-adic length scale are correlated so that also p-adic length scale measuring the size of the system would increase: larger spin singlets are formed.

2. The energies of states increase with h_{eff}. The increase of h_{eff} requires energy feed and h_{eff} can decrease spontaneously. Thermal energy can serve as an energy feed by inducing h_{eff} increasing transitions. Why does this increase not occur at higher temperatures and lead to larger spin singlet states than at low temperatures?

   Since this does not occur, thermal energy must exceed the binding energy of the state above a critical temperature and make it unstable. This requires that the binding energy of the state must decrease with increasing h_{eff}. Atomic binding energies satisfy this condition. They are proportional to $1/\hbar_{eff}^2$ and approach zero like $1/\hbar_{eff}^2$ and are stable only below a critical temperature determined by the ground state energy. Something similar should happen also now, which suggests that atomic binding energy of dark valence electrons is important.

6.2.3 What interactions should be taken into account?

In the Anderson's impurity model, Coulomb interaction between valence electrons and the interaction describing the hybridization are taken into account. In the TGD framework the situation can be more complex.

1. Certainly the coupling between dark valence electrons is important. In the presence of quantum coherence, one could perhaps approximate this interaction by using interaction strength Q^2e^2, where Q is the total charge of dark valence electrons of the cloud. Could one assume that Q^2e^2 defines in a good approximation the effective Planck constant as $\hbar_{em} = Q^2\alpha/\beta_0$? Could $\hbar_{em}$ define the binding energy scale of the dark valence electrons and reduce it by a factor $(\hbar/\hbar_{em})^2$ so that a thermal instability would be the outcome and the model would be in many respects be similar to the Anderson's impurity model.

Since the spin spin-interaction is essentially the interaction energy between two magnetic moments, it should be proportional to $\hbar_{eff}$ and would increase as dark valence electrons with increasing values of $\hbar_{eff}$ are stabilized. The stable value of $\hbar_{eff}$, determined by the Coulomb interaction terms for conduction electrons, should depend logarithmically on the temperature. The generalization of the Nottale hypothesis [E1] to the electromagnetic case implies $\hbar_{eff} \propto Q^2\alpha/\beta_0$. Therefore the parameter Q^2/β_0 measuring also the charge of the dark valence electron cloud should increase logarithmically with the inverse temperature.

2. In Anderson's impurity model, the attractive interaction between the conduction electrons and atoms is not taken into account. Can one forget the presence of atoms in the TGD framework? Assume that the dark valence electrons of the cloud behave like a single quantum coherent unit with total charge Q. The interaction strength for the mutual interactions of valence electrons would be Q^2e^2.

   If each dark valence electron is associated with a single atom (rather than with the atoms associated with the cloud), the effective charge Q_{eff} of the atom screened by the inner electrons is equal to $Q_{eff} = -1$ in the first approximation. The interaction strength for dark valence electron charge and atomic charge would be $QQ_{eff}e^2 = -Qe^2$. The interaction strength for the mutual interaction of valence electrons would dominate. Situation would be similar to that in the Anderson model.

6.2.4 Hadron physics analogy in the TGD framework

Ordinary hadron physics need not be enough as an analogy of Kondo effect in the TGD framework.

1. TGD predicts a hierarchy of scaled up versions of hadron physics associated with Mersenne primes and their Gaussian analogs [K21, K22]. Color confinement would occur always but at high energies the scale of confinement decreases as the size of the quarks decreases. The MB of the hadron would not disappear at high energies but its size decreases in a stepwise manner at p-adic length scales corresponding to Mersennes.

2. The possibility of having $h_{eff} > h$ allows to have a situation in which the Compton length and geometric size of say M_{89} hadron with 512 times higher mass than that of ordinary M_{107} hadron is the same as that of ordinary hadron [K21, K22].

   The model assumes that the p-adic length scale is not completely fixed by h_{eff}. The transition $h \rightarrow h_{eff} = 512h$ for M_{89} hadrons could serve as a TGD counterpart of color deconfinement for quarks, whose masses have increased by this factor.

   The number theoretic vision allows us to formulate this idea in a rather detailed way [L61].

   (a) A given extension of rationals with dimension $n = h_{eff}/h_0$ allows several ramified primes, which define possible p-adic length scales [L61] tentatively identified as p-adic lengths scales associated with the many-particle state assigned with the polynomial. For elementary particles there would be only a single ramified prime.

   (b) For a given value of p-adic length scale, one can have several values of $h_{eff}/h_0 = n$. Particles with different values of $h_{eff}/h_0 = n$ can have the same unique ramified prime. For two particles with the same ramified prime but with different values n_i, the ratio of p-adic length scales would be n_1/n_2.

   (c) If the particle belongs to a many-particle system possessing several ramified primes, also the ramified prime and the p-adic length scale characterizing the particle can change.

   (d) Assuming this picture, one can formulate the assumption that M_{89} hadrons appear as their dark variants in the situations, where indications for their existence can be found [K21, K22]. Dark variant of M_{89} hadron would have h_{eff} related by factor 512 to its non-dark variant.

3. Color confinement involves the increase of the strong coupling strength α_s. The proposed vision predicts a parton-hadron phase transition in which α_s is replaced by the coupling parameter $\beta_0/4\pi$ of the perturbation theory based on hadrons as fundamental objects.

   One can apply the analogy between color confinement and the Kondo effect also in the opposite direction. One can argue that valence quarks are analogous to the impurity electrons whereas sea quarks and gluons are analogous to the conduction electrons, which have transformed to dark valence electrons. Valence quarks would correspond to ordinary matter and sea partons to dark matter at MB. This suggests a new approach to hadron physics.

   As a matter of fact, the notion of a color magnetic body as a structure much larger than hadron itself has already made its appearance in TGD. The reason is that the Compton wavelengths of u and d current quarks are much longer than nucleus size and even nuclear size so that their proper place is naturally at the MB if the Compton length has geometric size as a classical space-time correlate.

4. Galois confinement [L35, L56, L57, L50] generalizes the notion of color confinement in the TGD framework, and is an essential element of the number theoretical view of TGD. It can be formulated at the level of 4-momenta of fermions and corresponds to momentum space description. Obviously, this description is especially well-suited in condensed matter physics.

   The extreme form of Galois confinement [L35, L67, L43, L59, L56, L57] states that all bound states are Galois confined. The Galois bound states are characterized by their binding energy. For a given extension they can exist only below a certain temperature and have a temperature dependent sice. The size of MB should increase and binding energy should decrease with the size so that the stable size of MB decreases with increasing temperature.

5. The energetics based objection against dark variants free particles can be circumvented in two ways. The trivial option is that all partons have $h_{eff} = h$. The non-trivial option is that bound states of dark partons are formed by Galois confinement and binding energy prevents spontaneous decay. The dark partons would be generated in the color confinement and become a part of a dark bound state or form a separate bound state as sea. Color confinement is closely related to Galois confinement. Does it make sense to say that it prevents the escape of the sea partons even if they are not Galois confined. In the collisions of hadrons, the collision energy can provide the metabolic energy feed and induce a phase transition increasing h_{eff} and this would indeed happen in the high energy collisions generating dark M_{89} hadrons interpreted in QCD as phase transition liberating quarks.

Consider now the application of this picture to the Kondo effect.

1. The hadronic analogy suggests that the logarithmic increase of the coupling between valence electron and impurity spins is a secondary phenomenon induced by the increase of $\hbar_{em}$ to which the magnetic interaction energy is proportional. One cannot speak of conduction electron scattering anymore. Rather, one should speak of the scattering of spin singlets as analogs of hadrons, whose size decreases at high temperatures as they approach impurity spins.

2. Assume that the sizes of MB of the spinless bound state increase at the $T = 0$ limit. The reduction of the size of MB would be due to both due the discrete p-adic length scale evolution and $h_{eff} = h_{em}Q^2\alpha/\beta_0$ evolution of the coupling strength for mutual interactions of valence-electrons as a quantum coherent unit. At high temperatures one would obtain free impurity spins as analogs of free quarks. Here one must take into account the possibility that some fraction of spins are genuinely free simply because the dark valence electron clouds contain only a fraction of valence electrons.

6.2.5 Some applications of the Kondo effect

Kondo effect according to TGD involves only very general assumptions such as hierarchy of Planck constants, the idea about $h \to h_{eff}$ when perturbation theory fails, and the instability of the bound states with $h_{eff} > h$ against too large thermal perturbations. Therefore the Kondo effect should generalize and have a strong resemblance with color confinement.

The Kondo effect indeed has several applications.

1. In heavy fermion systems (`https://rb.gy/hpkcyh`) the effective mass of electrons can increase by several orders. Also in hadron current quarks transform to much more massive consituent quarks, which involve not only the current quark but also the flux tube with color magnetic energy and the mass of the sea partons.

   Could the situation be the same now? The impurity spin valence electron is bound to conduction electrons, which have transformed to a sea of dark valence electrons. The effective mass of the impurity electron involves also the contribution from the magnetic energy and dark valence electrons.

2. In Kondo insulators (`https://rb.gy/ikl33x`) the valence electrons are bound to the flux tubes associated with the impurities and localization occurs. Current would not flow. There is an analogy with the state with no free quarks, which carry no color currents. Note however that now only spin currents vanish. This could allow charge currents as currents formed by the bound states of impurities and dark valence electron clouds.

7 Appendix

7.1 Comparison of TGD with other theories

Table 1 compares GRT and TGD and **Table 2** compares standard model and TGD.

7.2 Glossary and figures

The following glossary explains some basic concepts of TGD and TGD inspired biology.

- ***Space-time as surface***. Space-times can be regarded as 4-D surfaces in an 8-D space $M^4 \times CP_2$ obtained from empty Minkowski space (M^4) by adding four small dimensions (CP_2). The study of field equations characterizing space-time surfaces as "orbits" of 3-surfaces (3-D generalization of strings) forces the conclusion that the topology of space-time is non-trivial in all length scales.

- ***Geometrization of classical fields***. Both weak, electromagnetic, gluonic, and gravitational fields are known once the space-time surface in H as a solution of field equations is known.

  Many-sheeted space-time (see **Fig. 4**) consists of space-time sheets with various length scales with smaller sheets being glued to larger ones by ***wormhole contacts*** (see **Fig. 5**) identified as the building bricks of elementary particles. The sizes of wormhole contacts vary but are at least of CP_2 size (about 10^4 Planck lengths) and thus extremely small.

  Many-sheeted space-time replaces reductionism with ***fractality*** . The existence of scaled variants of physics of strong and weak interactions in various length scales is implied, and biology is especially interesting in this respect.

- ***Topological field quantization (TFQ)*** . TFQ replaces classical fields with space-time quanta. For instance, magnetic fields decompose into space-time surfaces of finite size representing flux tubes or -sheets. Field configurations are like Bohr orbits carrying "archetypal" classical field patterns. Radiation fields correspond to topological light rays or massless extremals (MEs), magnetic fields to magnetic flux quanta (flux tubes and sheets) having as primordial representatives "cosmic strings", electric fields correspond to electric flux quanta (e.g. cell membrane), and fundamental particles to CP_2 type vacuum extremals.

- ***Field body*** (FB) and ***magnetic body*** (MB). Any physical system has field identity - FB or MB - in the sense that a given topological field quantum corresponds to a particular source (or several of them - e.g. in the case of the flux tube connecting two systems).

	GRT	**TGD**
Scope of geometrization	classical gravitation	all interactions and quantum theory
Spacetime		
Geometry	abstract 4-geometry	sub-manifold geometry
Topology	trivial in long length scales	many-sheeted space-time
Signature	Minkowskian everywhere	also Euclidian
Fields		
classical	primary dynamical variables	induced from the geometry of H
Quantum fields	primary dynamical variables	modes of WCW spinor fields
Particles	point-like	3-surfaces
Symmetries		
Poincare symmetry	lost	Exact
GCI	true	true - leads to SH and ZEO
	Problem in the identication of coordinates	$H = M^4 \times CP_2$ provides preferred coordinates
Super-symmetry	super-gravitation	super variant of H: super-surfaces
Dynamics		
Equivalence Principle	true	true
Newton's laws and		
notion of force	lost	generalized
Einstein's equations	from GCI and EP	remnant of Poincare invariance at QFT limit of TGD
Bosonic action	EYM action	Kähler action + volume term
Cosmological constant	suggested by dark energy	length scale dependent coefficient of volume term
Fermionic action	Dirac action	Modified Dirac action for induced spinors
Newton's constant	given	predicted
Quantization	fails	Quantum states as modes of WCW spinor field

Table 1: Differences and similarities between GRT and TGD

	SM	TGD
Symmetries		
Origin	from empiria	reduction to CP_2 geometry
Color symmetry	gauge symmetry	isometries of CP_2
Color	analogous to spin	analogous to angular momentum
Ew symmetry	gauge symmery	holonomies of CP_2
Symmetry breaking	Higgs mechanism	CP_2 geometry
Spectrum		
Elementary particles	fundamental	consist of fundamental fermions
Bosons	gauge bosons, Higgs	gauge bosons, Higgs, pseudo-scalar
Fundamental fermions	quarks and leptons	quarks: leptons as local 3-quark composites
Dynamics		
Degrees of freedom	gauge fields, Higgs, and fermions	3-D surface geometry and spinors
Classical fields	gauge fields, Higgs	induced spinor connection
	SU(3) Killing vectors of CP_2	
Quantal degrees of freedom	gauge bosons,Higgs,	quantized induced spinor fields
Massivation	Higgs mechanism	p-adic thermodynamics with superconformal symmetry

Table 2: Differences and similarities between standard model and TGD

Maxwellian electrodynamics cannot have this kind of identification since the fields created by different sources superpose. Superposition is replaced with a set theoretic union: only the *effects* of the fields assignable to different sources on test particle superpose. This makes it possible to define the QFT limit of TGD.

- ***p-Adic physics*** [K24] as a physics of cognition and intention and the fusion of p-adic physics with real number based physics are new elements.
- ***Adelic physics*** [L15, L18] is a fusion of real physics of sensory experience and various p-adic physics of cognition.
- ***p-Adic length scale hypothesis*** states that preferred p-adic length scales correspond to primes p near powers of two: $p \simeq 2^k$, k positive integer.
- A ***Dark matter hierarchy*** realized in terms of a hierarchy of values of effective Planck constant $h_{eff} = nh_0$ as integers using $h_0 = h/6$ as a unit. Large value of h_{eff} makes possible macroscopic quantum coherence which is crucial in living matter.
- ***MB as an intentional agent using biological body (BB) as a sensory receptor and motor instrument*** . The personal MB associated with the living body - as opposed to larger MBs assignable with collective levels of consciousness - has a hierarchical onion-like layered structure and several MBs can use the same BB making possible remote mental interactions such as hypnosis [L4].
- ***Cosmic strings Magnetic flux tubes*** belong to the basic extremals of practically any general coordinate invariant action principle. Cosmic strings are surfaces of form $X^2 \times Y^2 \subset M^4 \times CP_2$. X^2 is analogous to string world sheet. Cosmic strings come in two varieties and both seem to have a deep role in TGD.

  Y^2 is either a complex or Lagrangian 2-manifold of CP_2. Complex 2-manifold carries monopole flux. For Lagrangian sub-manifold the Kähler form and magnetic flux and Kähler action vanishes. Both types of cosmic strings are are simultaneous extremals of both Kähler action and volume action: this holds true quite generally for preferred extremals.

Cosmic strings are unstable against perturbations thickening the 2-D M^4 projection to 3-D or 4-D: this gives rise to monopole (see **Fig. ??**) and non-monopole magnetic flux tubes. Using $M^2 \times Y^2$ coordinates, the thickening corresponds to the deformation for which $E^2 \subset M^4$ coordinates are not constant anymore but depend on Y^2 coordinates.

- ***Magnetic flux tubes and sheets*** serve as "body parts" of MB (analogous to body parts of BB), and one can speak about magnetic motor actions. Besides concrete motion of flux quanta/tubes analogous to ordinary motor activity, basic motor actions include the contraction of magnetic flux tubes by a phase transition possibly reducing Planck constant, and the change in thickness of the magnetic flux tube, thus changing the value of the magnetic field, and in turn the cyclotron frequency. Transversal oscillatory motions of flux tubes and oscillatory variations of the thickness of the flux tubes serve as counterparts for Alfwen waves.

  Reconnections of the U-shaped flux tubes allow two MBs to get in contact based on a pair of flux tubes connecting the systems and temporal variations of magnetic fields inducing motor actions of MBs favor the formation of reconnections.

  In hydrodynamics and magnetohydrodynamics reconnections would be essential for the generation of turbulence by the generation of vortices having monopole flux tube at core and Lagrangian flux tube as its exterior.

  Flux tube connections at the molecular level bring a new element to biochemistry making it possible to understand bio-catalysis. Flux tube connections serve as a space-time correlates for attention in the TGD inspired theory of consciousness.

- ***Cyclotron Bose-Einstein condensates (BECs)*** of various charged particles can accompany MBs. Cyclotron energy $E_c = hZeB/m$ is much below thermal energy at physiological temperatures for magnetic fields possible in living matter. In the transition $h \rightarrow h_{eff}$ E_c is scaled up by a fractor $h_{eff}/h = n$. For sufficiently high value of h_{eff} cyclotron energy is above thermal energy $E = h_{eff}\ ZeB/m$. Cyclotron Bose-Einstein condensates at MBs of basic biomolecules and of cell membrane proteins - play a key role in TGD based biology.

- ***Josephson junctions*** exist between two superconductors. In TGD framework, ***generalized Josephson junctions*** accompany membrane proteins such as ion channels and pumps. A voltage between the two super-conductors implies a ***Josephson current***. For a constant voltage the current is oscillating with the ***Josephson frequency*** . The Josephson current emits ***Josephson radiation***. The energies come as multiples of ***Josephson energy***.

  In TGD generalized Josephson radiation consisting of dark photons makes communication of sensory input to MB possible. The signal is coded to the modulation of Josephson frequency depending on the membrane voltage. The cyclotron BEC at MB receives the radiation producing a sequence of resonance peaks.

- ***Negentropy Maximization Principle*** (NMP). NMP [K20] [L46] is the variational principle of consciousness and generalizes SL. NMP states that the negentropy gain in SFR is non-negative and maximal. NMP implies SL for ordinary matter.

- ***Negentropic entanglement*** (NE). NE is possible in adelic physics and NMP does not allow its reduction. NMP implies a connection between NE, the dark matter hierarchy, p-adic physics, and quantum criticality. NE is a prerequisite for an experience defining abstraction as a rule having as instances the state pairs appearing in the entangled state.

- ***Zero energy ontology (ZEO)*** In ZEO physical states are pairs of positive and negative energy parts having opposite net quantum numbers and identifiable as counterparts of initial and final states of a physical event in the ordinary ontology. Positive and negative energy parts of the zero energy state are at the opposite boundaries of a ***causal diamond*** (CD, see **Fig. 12**)) defined as a double-pyramid-like intersection of future and past directed light-cones of Minkowski space.

CD defines the "spot-light of consciousness": the contents of conscious experience associated with a given CD is determined by the space-time sheets in the embedding space region spanned by CD.

- ***SFR*** is an acronym for state function reduction. The measurement interaction is universal and defined by the entanglement of the subsystem considered with the external world [L27] [K41]. What is measured is the density matrix characterizing entanglement and the outcome is an eigenstate of the density matrix with eigenvalue giving the probability of this particular outcome. SFR can in principle occur for any pair of systems.

  SFR in ZEO solves the basic problem of quantum measurement theory since the zero energy state as a superposition of classical deterministic time evolutions (preferred extremals) is replaced with a new one. Individual time evolutions are not made non-deterministic.

  One must however notice that the reduction of entanglement between fermions (quarks in TGD) is not possible since Fermi- and als Bose statistics predicts a maximal entanglement. Entanglement reduction must occur in WCW degrees of freedom and they are present because point-like particles are replaced with 3-surfaces. They can correspond to the number theoretical degrees of freedom assignable to the Galois group - actually its decomposition in terms of its normal subgroups - and to topological degrees of freedom.

- ***SSFR*** is an acronym for "small" SFR as the TGD counterpart of weak measurement of quantum optics and resembles classical measurement since the change of the state is small [L27] [K41]. SSFR is preceded by the TGD counterpart of unitary time evolution replacing the state associated with CD with a quantum superposition of CDs and zero energy states associated with them. SSFR performs a localization of CD and corresponds to time measurement with time identifiable as the temporal distance between the tips of CD. CD is scaled up in size - at least in statistical sense and this gives rise to the arrow of time.

  The unitary process and SSFR represent also the counterpart for Zeno effect in the sense that the passive boundary of CD as also CD is only scaled up but is not shifted. The states remain unchanged apart from the addition of new fermions contained by the added part of the passive boundary. One can say that the size of the CD as analogous to the perceptive field means that more and more of the zero energy state at the passive boundary becomes visible. The active boundary is however both scaled and shifted in SSFR and states at it change. This gives rise to the experience of time flow and SSFRs as moments of subjective time correspond to geometric time as a distance between the tips of CD. The analog of unitary time evolution corresponds to "time" evolution induced by the exponential of the scaling generator L_0. Time translation is thus replaced by scaling. This is the case also in p-adic thermodynamics. The idea of time evolution by scalings has emerged also in condensed matter physics.

- ***BSFR*** is an acronym for "big" SFR, which is the TGD counterpart of ordinary state function reduction with the standard probabilistic rules [L27] [K41]. What is new is that the arrow of time changes since the roles of passive and active boundaries change and CD starts to increase in an opposite time direction.

  This has profound thermodynamic implications. Second law must be generalized and the time corresponds to dissipation with a reversed arrow of time looking like self-organization for an observed with opposite arrow of time [L25]. The interpretation of BSFR is as analog of biological death and the time reversed period is analogous to re-incarnation but with non-standard arrow of time. The findings of Minev *et al* [L23] give support for BSFR at atomic level. Together with h_{eff} hierarchy BSFR predicts that the world looks classical in all scales for an observer with the opposite arrow of time.

7.3 Figures

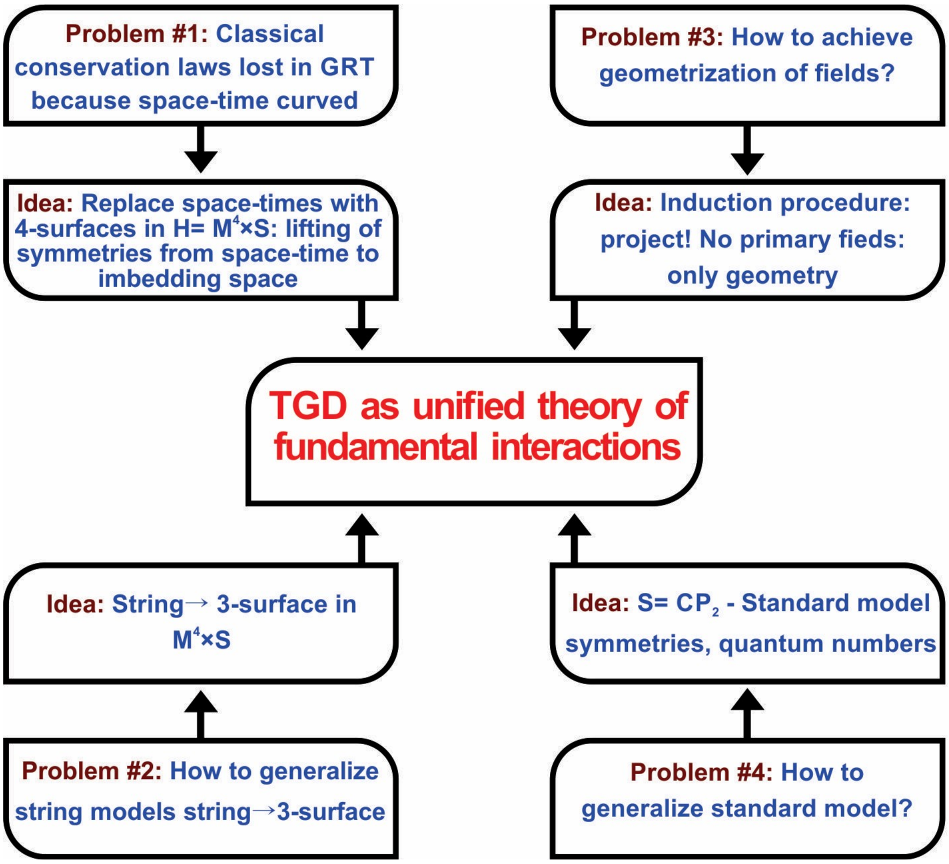

Figure 1: The problems leading to TGD as their solution.

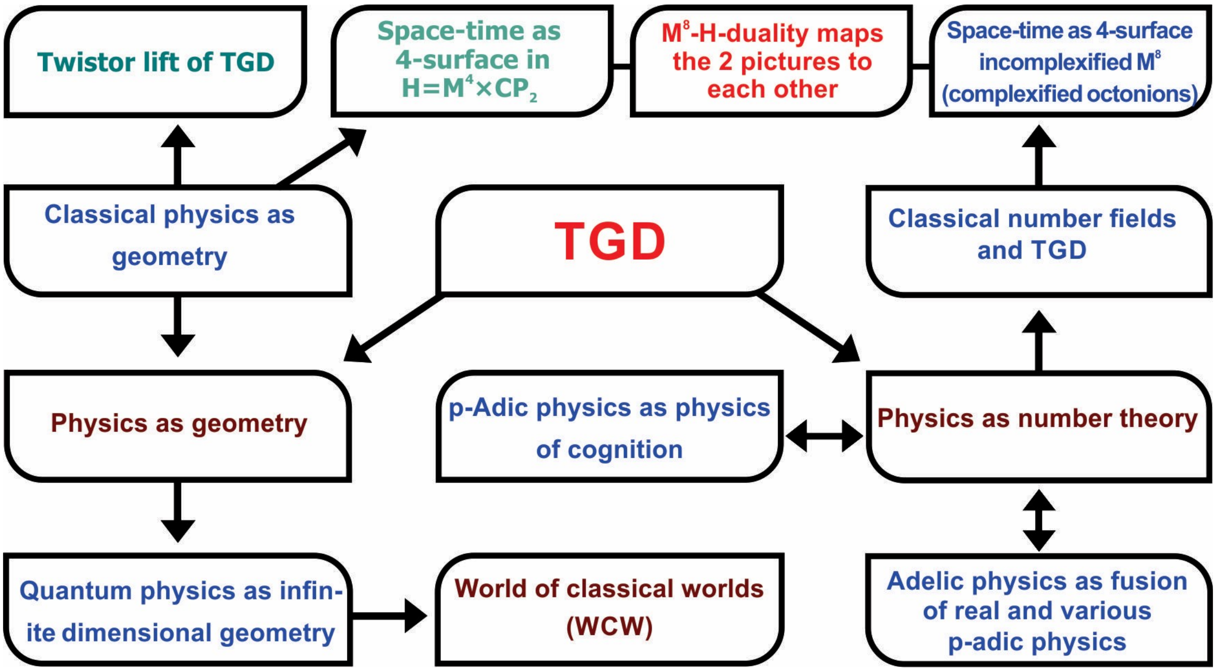

Figure 2: TGD is based on two complementary visions: physics as geometry and physics as number theory.

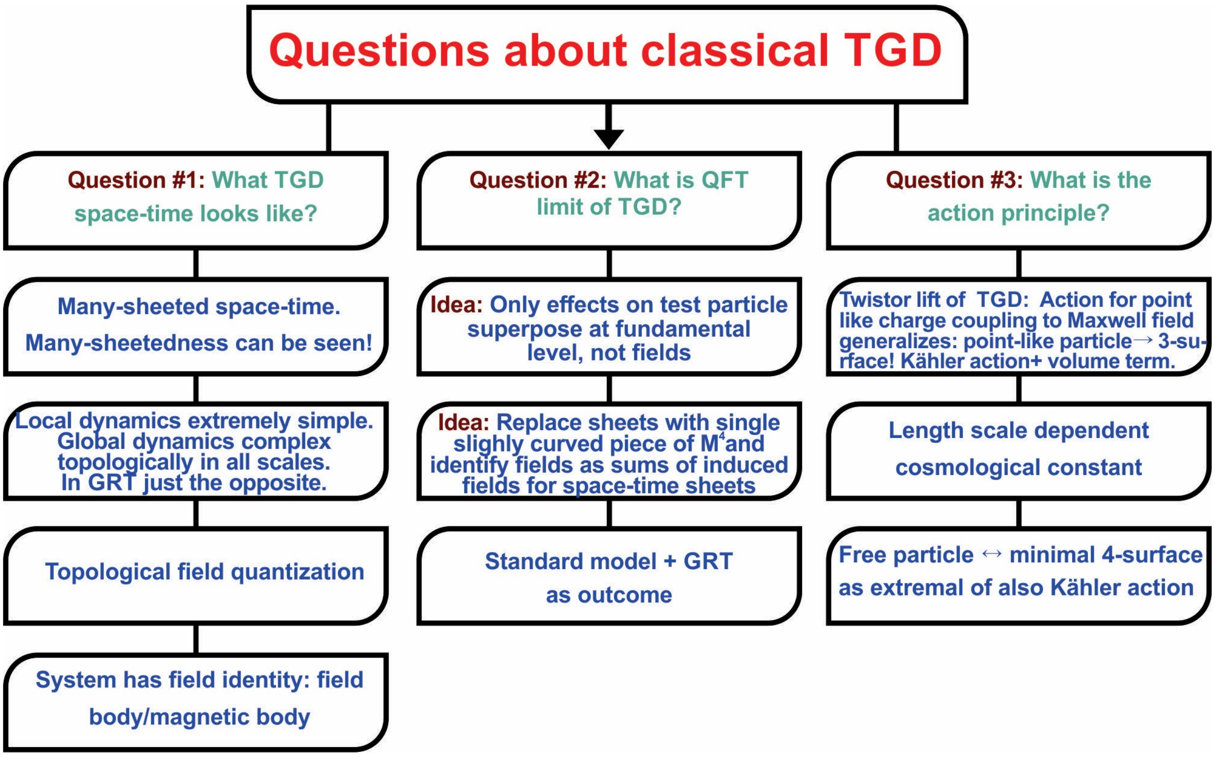

Figure 3: Questions about classical TGD.

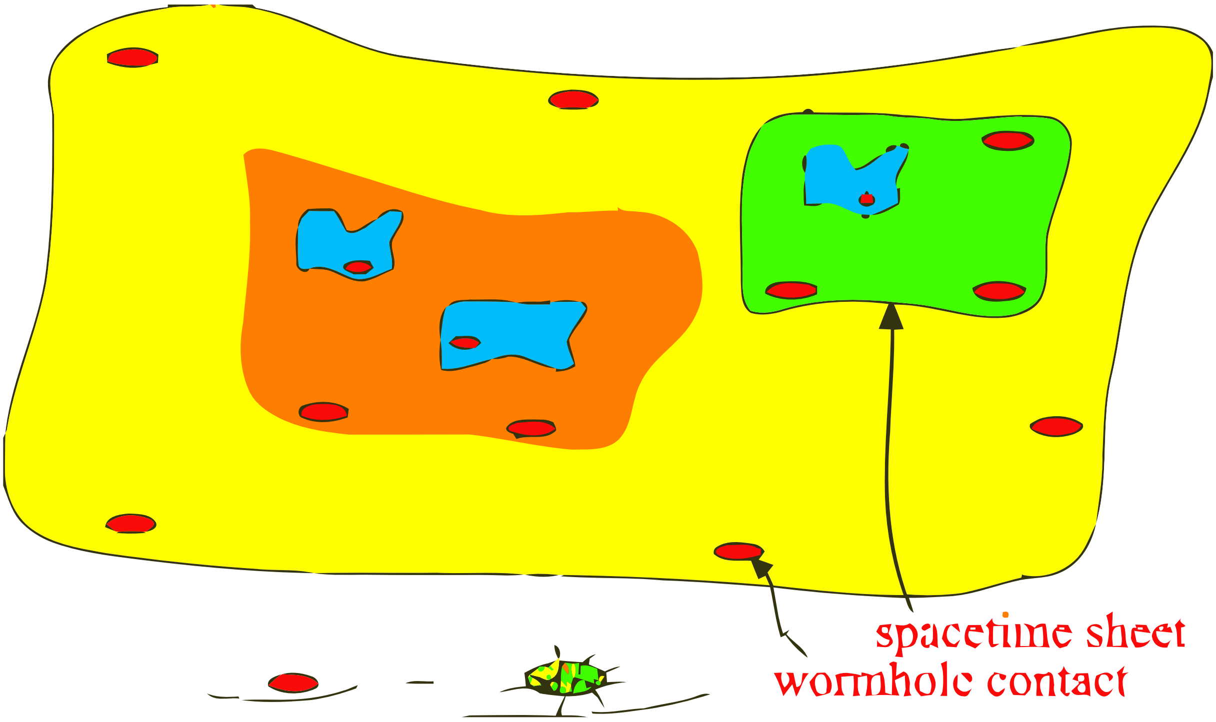

Figure 4: Many-sheeted space-time.

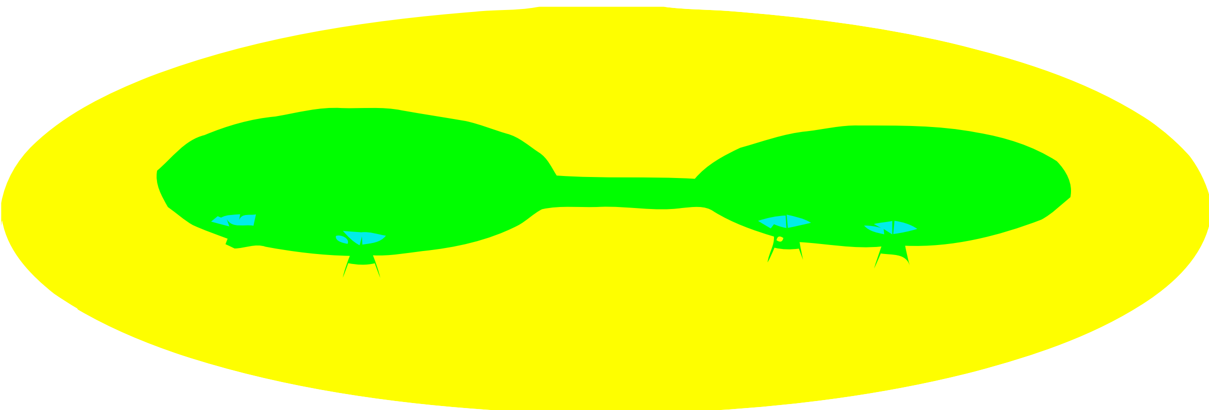

Figure 5: Wormhole contacts.

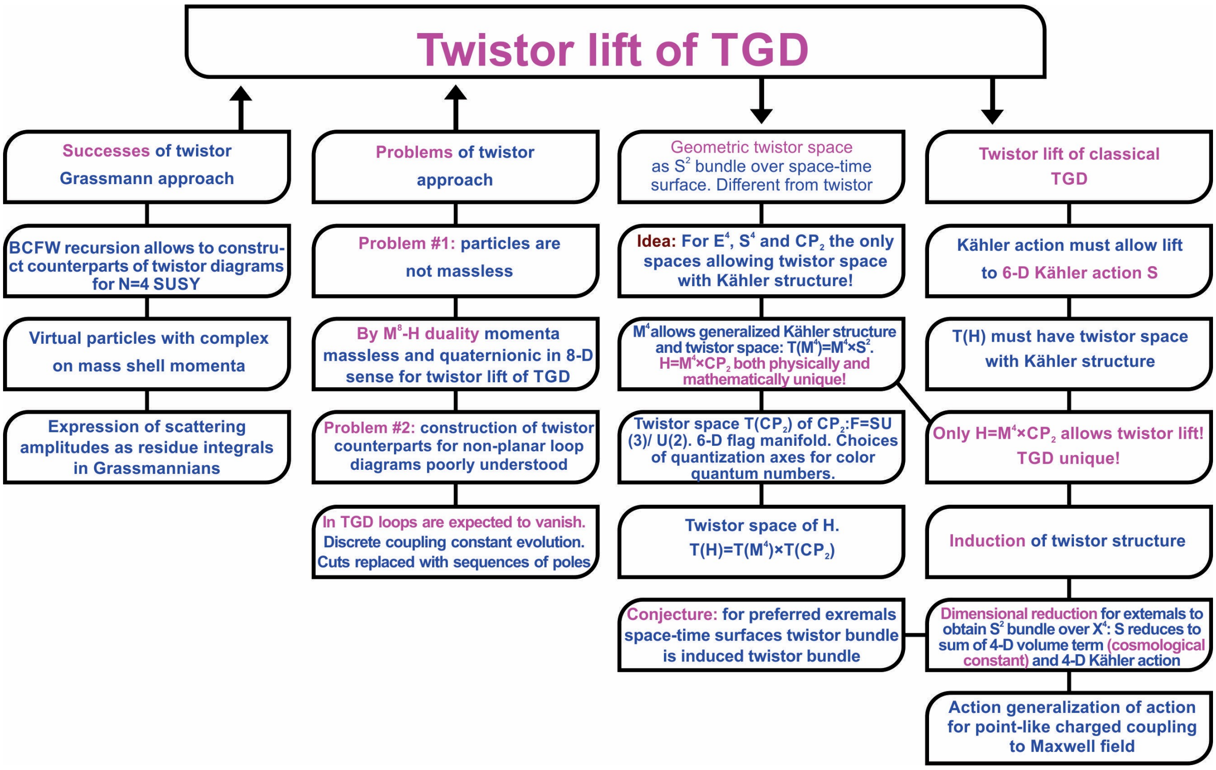

Figure 6: Twistor lift

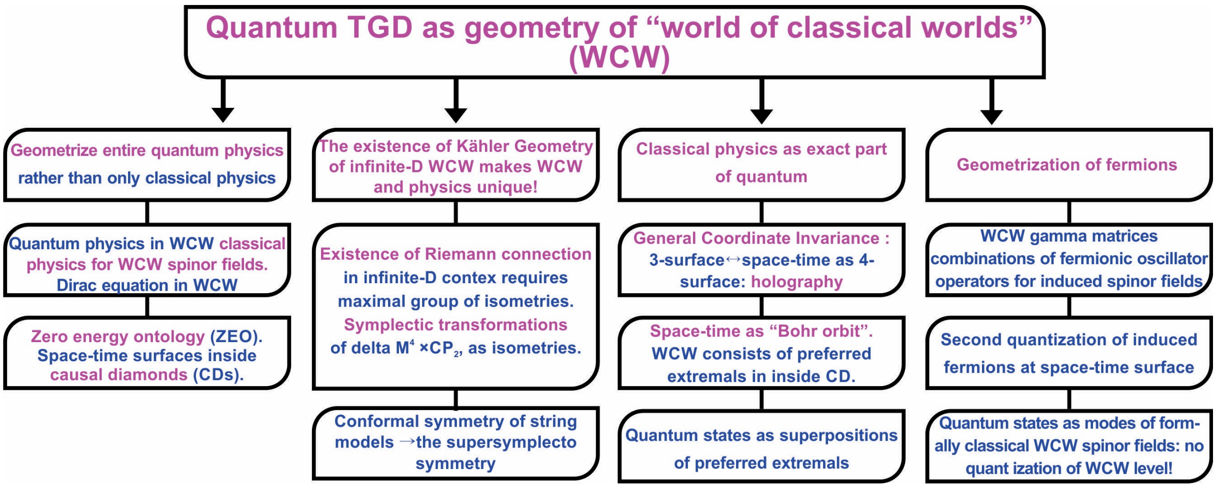

Figure 7: Geometrization of quantum physics in terms of WCW

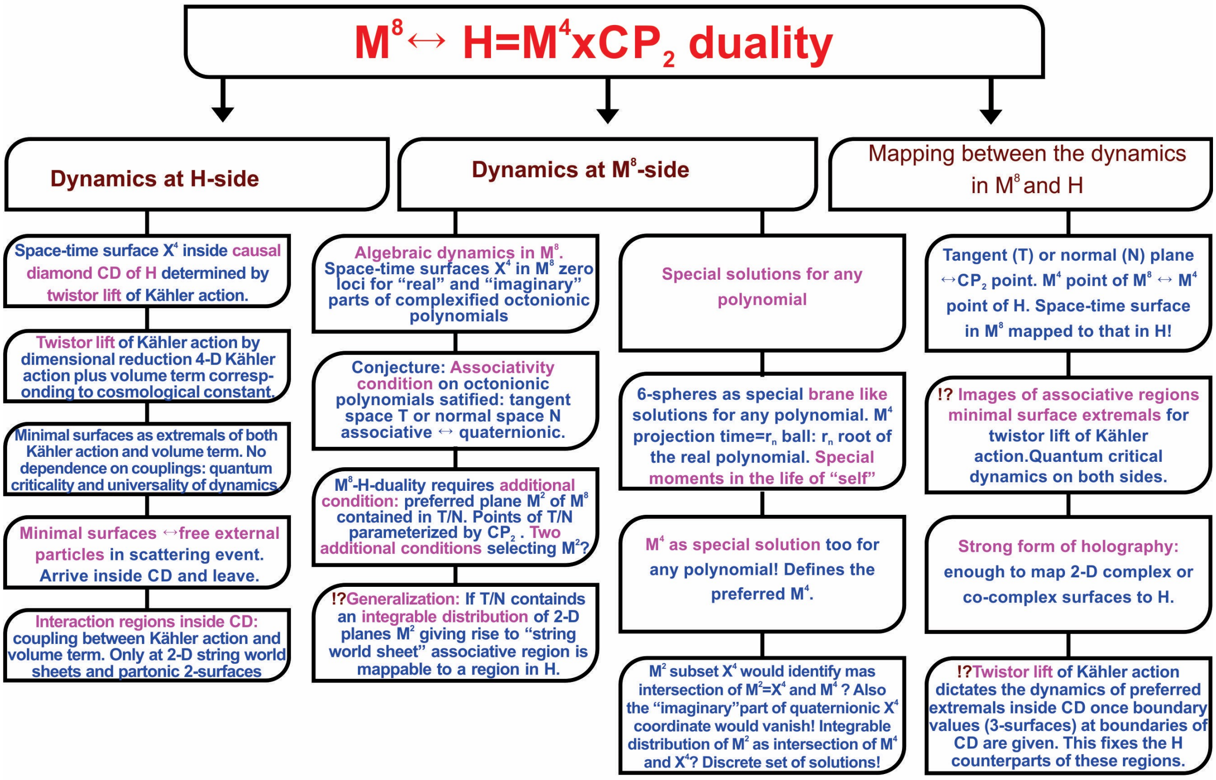

Figure 8: $M^8 - H$ duality

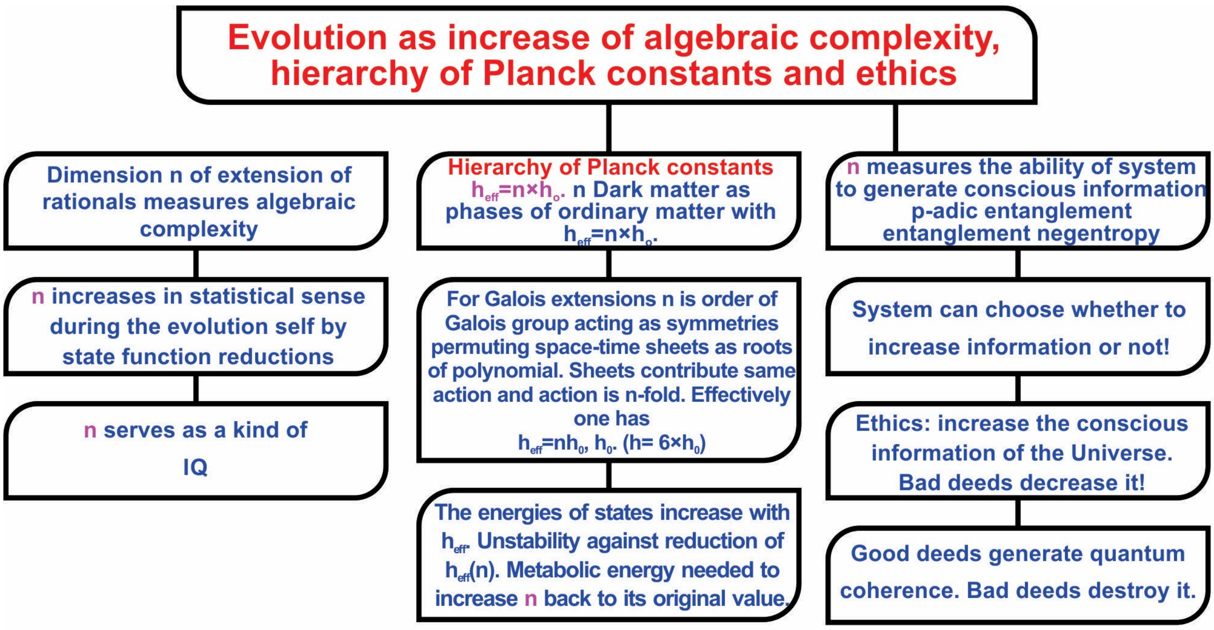

Figure 9: Number theoretic view of evolution

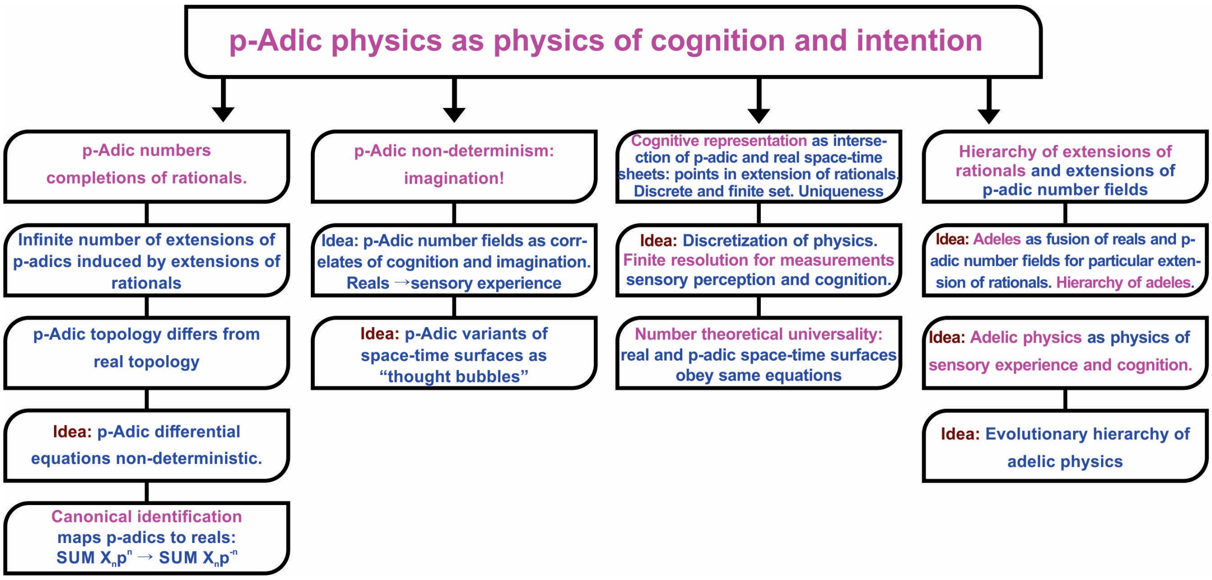

Figure 10: p-Adic physics as physics of cognition and imagination.

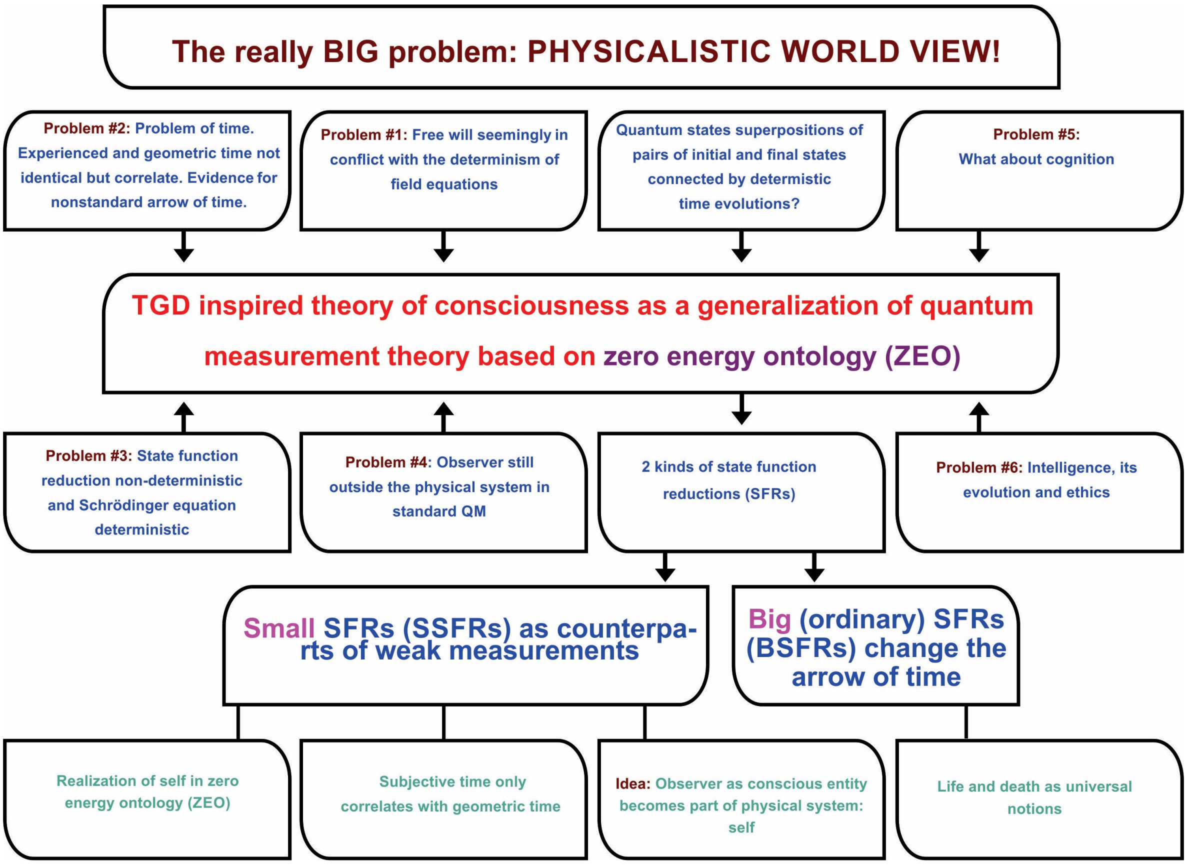

Figure 11: Consciousness theory from quantum measurement theory

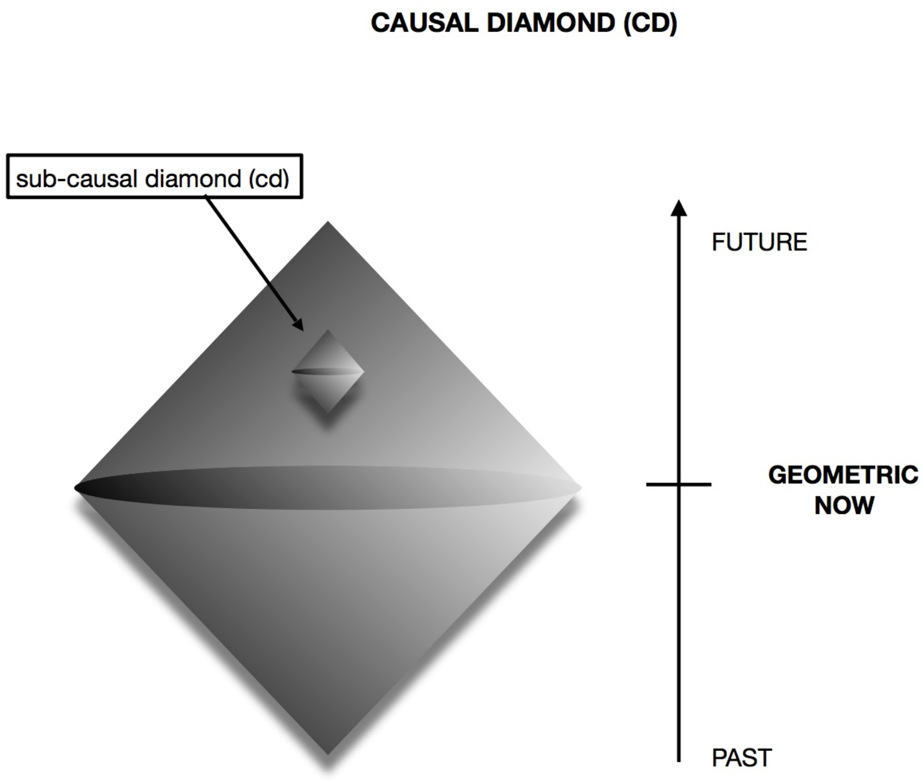

Figure 12: Causal diamond

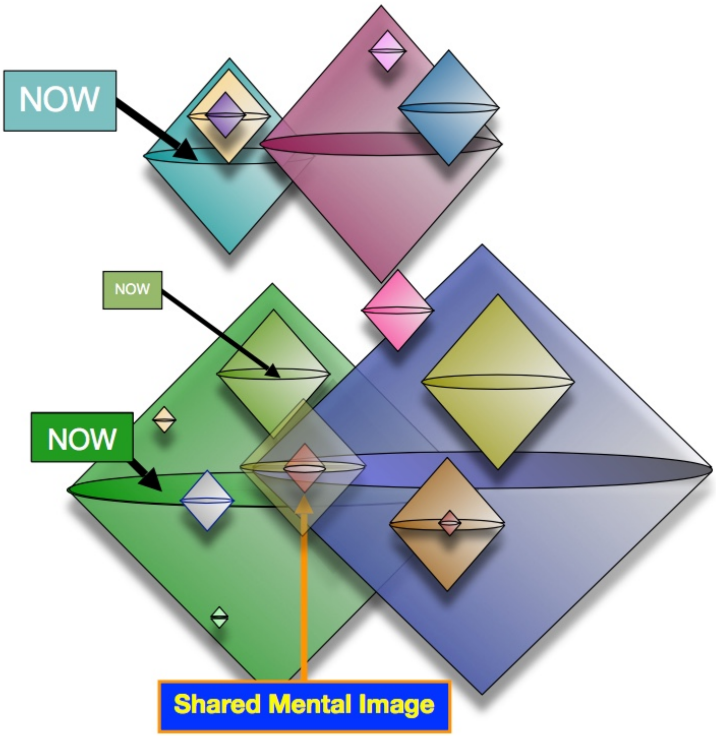

Figure 13: CDs define a fractal "conscious atlas"

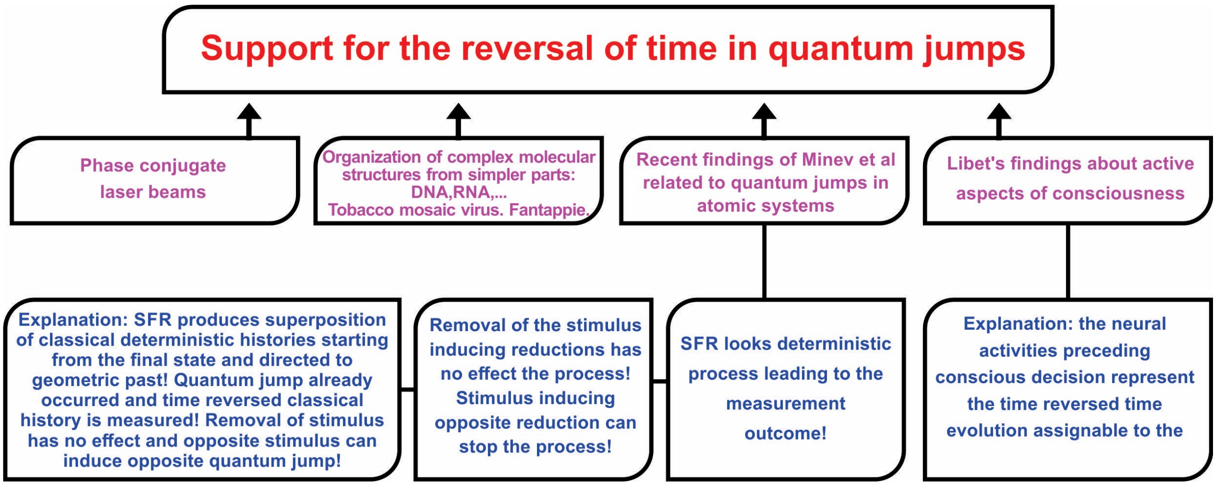

Figure 14: Time reversal occurs in BSFR

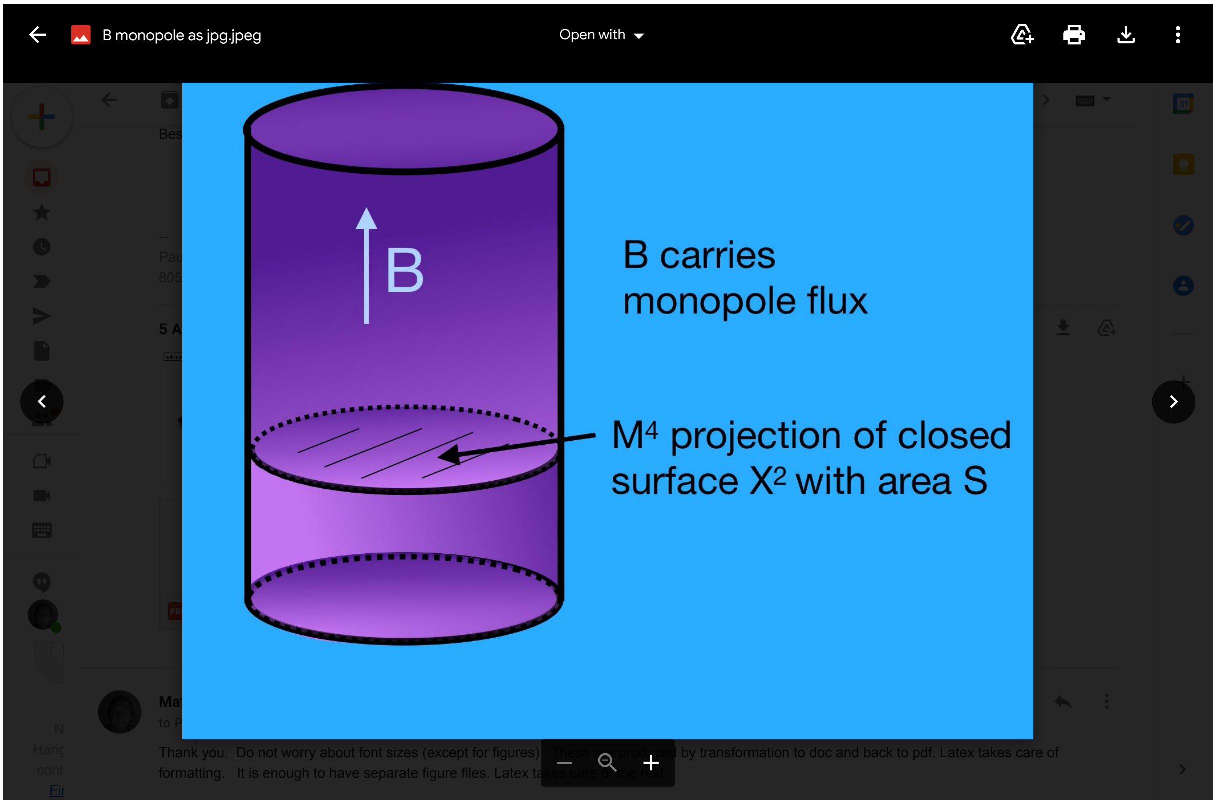

Figure 15: The M^4 projection of a closed surface X^2 with area S defining the cross section for monopole flux tube. Flux quantization $e \oint B \cdot dS = eBS = kh$ at single sheet of n-sheeted flux tube gives for cyclotron frequency $f_c = ZeB/2\pi m = khZ/2\pi mS$. The variation of S implies frequency modulation.

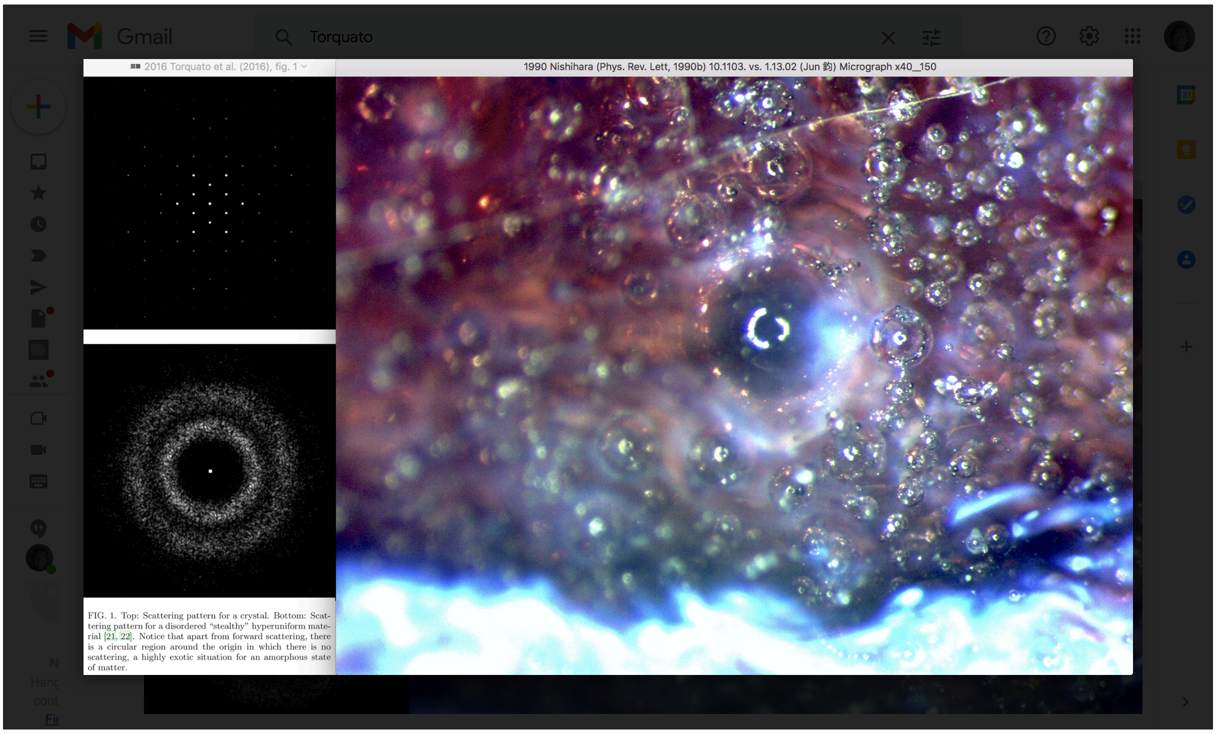

Figure 16: The scattering from a hyperuniform amorphous material shows no scattering in small angles apart from the forward peak (`https://cutt.ly/ZWyLgjk`). This is very untypical in amorphous matter and might reflect the diffraction pattern of dark photons at the magnetic body of the system.

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