General View About Physics in Many-Sheeted Space-Time: Part I

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Abstract

This chapter is first part of the discussion devoted to the notion of many-sheeted space-time. The notion of many-sheeted space-time used is roughly that as it was around 1990 and is thus necessarily out-of-date in many respects. Text only refers to the recent picture when needed. Topological condensation and somewhat questionable notion of topological evaporation represent the basic new concepts of TGD and an attempt to formulate a general qualitative theory of the topological condensation and evaporation and TGD based space-time concept is made.

The fusion of real and various p-adic physics to single coherent whole by generalizing the notion of number, the generalization of the notion of the imbedding space to allow a mathematical representation of dark matter hierarchy based on dynamical and quantized Planck constant, parton level formulation of TGD using light-like 3-surfaces as basic dynamical objects, and so called zero energy ontology force to generalizes considerably the view about space-time. These developments are discussed in the next chapter.

The topics to be discussed in the sequel will be following.

1. The general structure of topological condensate

The question what 3-space looks like in various scales and end up to a purely topological description for the generation of structures. Topological arguments imply a finite size for non-vacuum 3-surfaces and the conservation of the gauge and gravitational fluxes requires that 3-surface feeds these fluxes to a larger 3-surface via # contacts situated near the boundaries of the 3-surface. Renormalization group invariance (RGI) hypothesis suggests that 3-surfaces with all sizes are important in the functional integral and this leads to the idea of the many-sheeted space-time with hierarchical, fractal like structure such that each level of the hierarchy corresponds to a characteristic length scale.

The notion of boundary has turned out to be problematic: there are good reasons to assume that the natural boundary conditions for Kähler action do not allow them! Instead space-time sheet is replaced by its double covering with sheet glued together along their common boundary. The 3-D light-like orbits of wormhole throats at which the induced metric changes its signature however act effectively as boundaries. The notion of many-sheeted space-time as topological condensate however survives albeit in generalized form.

2. Topological field quantization

The general space-time picture suggested by RGI hypothesis can be justified mathematically. Due to the compactness of CP_2, a general space-time surface representable as a map $M^4 \to CP_2$ decomposes into regions, "topological field quanta", characterized by certain vacuum quantum numbers and 3-surface is in general unstable against the decay to disjoint components along the boundaries of the field quanta.

Topological field quanta have finite size depending on the values of the vacuum quantum numbers: the size increases as the values of the vacuum quantum numbers increase. Topological field quantum is therefore a good candidate for a quantum coherent system provided some Bose Einstein condensate or quantum coherent state is available. The BE condensate or coherent state of the light # contacts (wormhole contacts) near the boundaries of the topological field quantum is a good candidate in this respect.

The requirement of the gauge charge conservation in implies the hierarchical structure of the topological condensate: gauge fluxes must go somewhere from the outer boundaries of the topological field quantum with finite size and this "somewhere" must be a larger topological field quantum, which in turn feeds its gauge fluxes to a larger topological field quantum,.... Of course, the nonlinearity of the theory could allow vacuum charge densities which can cancel the net charge near boundaries. The recent view about quantum TGD however supports the conclusion that vacuum currents are light-like and do not contribute to charge renormalization. This provides a justification for the notion of p-adic coupling constant evolution.

Topological field quanta allow discrete scalings as a dynamical symmetry. p-Adic length scale hypothesis states that the allowed scaling factors correspond to powers of $\sqrt{p}$, where the prime p satisfies $p \simeq 2^k$, k integer with prime values favored. p-Adic fractality (actually multi-p-fractality) can be justified more rigorously by a precise formulation for the fusion of real and various p-adic physics based on the generalization of the notion of number.

3. General physical consequences of new view about space-time

The physical consequences of the new space-time picture are nontrivial at all length scales.

1. A natural interpretation for the hierarchical structure is in terms of bound state formation. Quarks condense to form hadrons, nucleons condense to form atomic nuclei, nuclei and electrons condense to form atoms, how atoms condense to form molecules, and so on. One ends up with a general picture for the topology of 3-space associated with, say, solid state and with the idea that even the macroscopic bodies of the everyday world correspond to topologically condensed 3-surfaces.
2. The join of 3-surfaces along their boundaries (or along boundaries of Minkowskian or Euclidian regions in the recent picture) defines a new kind of interaction, which has in fact has been used in phenomenological modelling of chemical reactions. Usually chemical bond is believed to result from Schrödinger equation. At the macroscopic level this interaction is rather familiar to us since it means that two macroscopic bodies just touch each other. If one gives up the notion of boundary, join along boundaries bonds are replaced with magnetic flux tubes.
3. In TGD context there are purely topological necessary conditions for quantum coherence and a topological description for dissipative phenomena. The formation of the join along boundaries bonds plays a decisive role in the description and this process provides a universal manner to generate macroscopic quantum systems. There is also a topological description for the formation of the supra phases and the phase of the order parameter of the supra phase ground state contains information about the homotopy of the join along boundaries condensate.

4. Gauge bosons and Higgs boson as wormhole contacts

The proper understanding of the concepts of gauge charges and fluxes and their gravitational counterparts in TGD space-time has taken a lot of efforts.

1. Wormhole (#-) contact is the key notion. Wormhole contacts can be regarded as particles carrying classical charges defined by the gauge fluxes but behaving as extremely tiny dipoles quantum mechanically in the case that gauge charge is conserved. Gauge fluxes and gauge charges assignable to light-like 3-D surfaces (wormhole throats, elementary particle horizons, causal determinants) surrounding a topologically condensed CP_2 type extremals can be identified as the quantum numbers assignable to fermionic oscillator operators generating the state associated with horizon (wormhole throat) identifiable as a parton.
2. Quantum classical correspondence requires that commuting classical gauge charges are quantized and this is expected to be true by the generalized Bohr orbit property of the space-time surface.
3. Both gauge bosons and Higgs boson must be identified as wormhole contacts whereas elementary fermions correspond to wormhole throats associated with topologically condensed CP_2 type vacuum extremals. Gravitons in turn correspond to string like objects formed by pairs of wormhole contacts connected by a flux tube.

This picture has later generalize so that it applies to all particles. The assumption that wormhole contacts carry Kähler magnetic monopole flux forces to assume the presence of second wormhole contact so that one obtains closed magnetic flux tube. The other wormhole contact carries neutrino pairs neutralizing the weak quantum numbers of the particle above weak scale.

5. The interpretation of long range weak and color gauge fields

In TGD gravitational fields are accompanied by long ranged electro-weak and color gauge fields. The only possible interpretation is that there exists a p-adic hierarchy of color and electro-weak physics such that weak bosons are massless below the p-adic length scale determining the mass scale of weak bosons. By quantum classical correspondence classical long ranged gauge fields serve as space-time correlates for gauge bosons below the p-adic length scale in question.

The unavoidable long ranged electro-weak and color gauge fields are created by dark matter and dark particles can screen dark nuclear electro-weak charges below the weak scale. Above this scale vacuum screening occurs as for ordinary weak interactions. Dark gauge bosons are massless below the appropriate p-adic length scale but massive above it and $U(2)_{ew}$ is broken only in the fermionic sector. For dark copies of ordinary fermions masses are essentially identical with those of ordinary fermions.

This interpretation is consistent with the standard elementary particle physics for visible matter apart from predictions such as the possibility of p-adically scaled up versions of ordinary quarks predicted to appear already in ordinary low energy hadron physics. The most interesting implications are seen in longer length scales. Dark variants of ordinary valence quarks and gluons and a scaled up copy of ordinary quarks and gluons are predicted to emerge already in ordinary nuclear physics. Chiral selection in living matter suggests that dark matter is an essential component of living systems so that non-broken $U(2)_{ew}$ symmetry and and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

In this chapter the above vision is discussed in detail. As an application a simple model of color confinement is discussed using the general properties of the induced (classical) color gauge field, in particular the fact that its holonomy group is Abelian. The more recent development have brought new elements to the picture such as understanding how the em charges of fermions can be well-defined in absence of classical W boson fields. What happens is that spinor modes are localized to 2-D surfaces - string worlds sheets and possibly also partonic 2-surfaces. This gives very concrete connection with string models.

1 Introduction

The concept of topological condensation unifies two disparate approaches to TGD, namely TGD as a Poincare invariant theory of gravitation and TGD as a generalization of the string model. The idea is that classical 3- space with matter can be regarded as a 3-surface obtained by "gluing" particle like 3-surfaces to the background 3-surface with possibly macroscopic size: resulting topological in-homogenuities correspond to matter. The "gluing" of two n-manifolds together by topological sum means the following operation: drill spherical holes to both n-manifolds and connect the resulting boundary components S^{n-1} with a tube $D^1 \times S^{n-1}$. Of course, several # contacts, which are tiny "wormholes" connecting two parallel space-time sheets, are expected to be present in the general case.

1.1 Various Types Of Topological Condensation

One can in fact distinguish between three kinds of topological condensation.

1. 3-dimensional topological condensation, which is expected to give rise to the formation of bound states (not necessary all possible bound states).

2. 4-dimensional topological condensation, which results from the properties of the Kähler action: the minimizing four surface associated with a given set of 3-surfaces is in general connected so that long range interactions are generated between the 3-surfaces. This mechanism is in principle all what is needed to generate the so called classical space-time. Although the physical state can consist of arbitrarily many disjoint 3-surfaces, the space-time associated with these surfaces is connected and resembles the "classical" space-time, when topological inhomogenuities are smoothed out. It should be noticed that 4-dimensional topological condensation corresponds to unstable 3-dimensional topological condensation. For the visualization purposes, one can consider a simplified example: instead of 3-surfaces consider strings so that space-time is replaced with a two-surface having strings as its boundaries.

3. 2-dimensional topological condensation: boundaries of the 3- surfaces are joined together by a tube $D^1 \times D^2$. This process will be referred as a formation of join along boundaries bonds.

There are also reasons to suspect that the actual macroscopic 3-space is not connected but corresponds to a large macroscopic 3-surface, classical 3-space, plus a gas of small particle like 3-surfaces, "Baby Universes". It is to be expected that the effects related to the vapor phase particles are very small. An idealization is obviously needed in order to obtain something resembling the topologically trivial 3-space of the standard theories: topological inhomogenuities of size smaller than a given length scale L are smoothed out and their presence is described using various currents, such as energy momentum tensor, gauge currents and particle number currents. To be precise, this works only provided one takes the limit $L \to \infty$ since TGD space-time could well be many sheeted in arbitrarily long length scales.

One important deviation from the original picture is that 3-surfaces very probably cannot have boundaries. Space-time sheets are replaced with double sheets obtained by glueing two sheets with boundaries together. The light-like 3-surfaces at which the signature of induced metric changes from Minkowskian to Euclidian however replace genuine boundaries as "causal boundaries" or as real boundaries of Minkowskian/Euclidian regions. This double-sheetedness is required also by the recent view about elementary particles.

1.2 Implications Of The Topological Non-Triviality Of Macroscopic Space-Time

If one accepts that 3-space is topologically nontrivial, one must sooner or later end up asking following questions. What does 3-space actually look like in various scales? What are the general physical consequences of the new space time concept? Are they seen at elementary particle level only or perhaps at atomic, molecular, etc. levels? What is the 3-topology of the solid/liquid/gas state? What about macroscopic bodies: what do they correspond topologically?

In the following the general ideas about the topological condensation are discussed. These ideas have developed gradually in parallel with the development of the configuration space geometry and Quantum TGD, through the study of the extremals of Kähler action and through the attempts to apply TGD inspired ideas to many not so well understood phenomena like Higgs mechanism or more generally, particle massivation, color confinement, super fluidity, super conductivity, hydrodynamic turbulence, etc.. The ideas to be represented may look rather wild, when encountered outside the context defined by twenty years of personal work with many trials and errors and moments of discovery. It is the internal consistency rather than quantitative details, as well as the radically new approach provided to the problems of even macroscopic physics, which makes the scenario so exciting.

1.3 Topics Of The Chapter

The topics to be discussed in the sequel will be following:

1. The question what 3-space looks like in various scales and end up to a purely topological description for the

   generation of structures. Topological arguments imply a finite size for non-vacuum 3-surfaces and the conservation of the gauge and gravitational fluxes requires that 3-surface feeds these fluxes to a larger 3-surface via # contacts situated near the boundaries of the 3-surface. Renormalization group invariance (RGI) hypothesis suggests that 3-surfaces with all sizes are important in the functional integral and this leads to the idea of the many-sheeted space-time with hierarchical, fractal like structure such that each level of the hierarchy corresponds to a characteristic length scale.

   RGI actually has actually rather concrete meaning: Kähler action contains no coupling constants so that it is not possible to speak about coupling constants and coupling constant evolution at the level of many-sheeted space-time. Coupling constant evolution emerges only as discrete p-adic coupling constant evolution at the level of effective space-time obtained by replacing the many-sheeted space-time with M^4 and endowed with effective metric whose deviation form M^4 metric is sum of the deviations of the induced metrics of space-time sheets from M^4 metric. Gauge potentials are defined in the same manner. This defines the counterpart of GRT space-time carrying standard model gauge fields and particles.

2. The general space-time picture suggested by RGI hypothesis can be justified mathematically. Due to the compactness of CP_2, a general space-time surface representable as a map $M^4 \to CP_2$ decomposes into regions, "topological field quanta", characterized by certain vacuum quantum numbers and 3-surface is in general unstable against the decay to disjoint components along the boundaries of the field quanta. Topological field quanta have finite size depending on the values of the vacuum quantum numbers: the size increases as the values of the vacuum quantum numbers increase. Topological field quantum is therefore a

good candidate for a quantum coherent system provided some Bose Einstein condensate or quantum coherent state is available. The BE condensate or coherent state of the light # contacts near the boundaries of the topological field quantum is a good candidate in this respect.

The requirement of the gauge charge conservation in turn implies the hierarchical structure of the topological condensate: gauge fluxes must go somewhere from the outer boundaries of the topological field quantum with finite size and this “somewhere” must be a larger topological field quantum, which in turn feeds its gauge fluxes to a larger topological field quantum,.... Of course, the nonlinearity of the theory could allow vacuum charge densities which can cancel the net charge near boundaries.

Most importantly, topological field quanta allow discrete scalings as a dynamical symmetry. p-Adic length scale hypothesis states that the allowed scaling factors correspond to powers of $\sqrt{p}$, where the prime p satisfies $p \simeq 2^k$, k integer with prime values favored. p-Adic fractality (actually multi-p-fractality) can be justified more rigorously by a precise formulation for the fusion of real and various p-adic physics based on the generalization of the notion of number [K24].

The physical consequences of the new space-time picture are nontrivial at all length scales.

(a) A natural interpretation for the hierarchical structure is in terms of bound state formation. Quarks condense to form hadrons, nucleons condense to form atomic nuclei, nuclei and electrons condense to form atoms, how atoms condense to form molecules, and so on. One ends up with a general picture for the topology of 3-space associated with, say, solid state and with the idea that even the macroscopic bodies of the everyday world correspond to topologically condensed 3-surfaces.

(b) The join of 3-surfaces along their boundaries (replaced by causal boundaries in the recent picture) defines a new kind of interaction, which in fact has been used in phenomenological modelling of and usually believed to result from Schrödinger equation. At the macroscopic level this interaction is rather familiar to us since it means that two macroscopic bodies just touch each other!

(c) The possibility to understand general qualitative features of the charge renormalization topologically in the proposed scenario for space-time, is considered. This rough vision represents one of the oldest strata in the evolution of TGD: in [K3] the recent view about space-time correlates of gauge charges is developed.

(d) In TGD context there are purely topological necessary conditions for quantum coherence and a topological description for dissipative phenomena. The formation of the join along boundaries bonds plays a decisive role in the description and this process provides a universal manner to generate macroscopic quantum systems.

(e) There is also a topological description for the formation of the supra phases and the phase of the order parameter of the supra phase ground state contains information about the homotopy of the join along boundaries condensate.

The proper understanding of the concepts of gauge charges and fluxes and their gravitational counterparts in TGD space-time has taken a lot of efforts. At the fundamental level gauge charges assignable to light-like 3-D elementary particle horizons surrounding a topologically condensed CP_2 type extremals can be identified as the quantum numbers assignable to fermionic oscillator operators generating the state associated with horizon identifiable as a parton. Quantum classical correspondence requires that commuting classical gauge charges are quantized and this is expected to be true by the generalized Bohr orbit property of the space-time surface.

The most dramatic prediction obvious from the beginning but mis-interpreted for about 26 years is the presence of long ranged classical electro-weak and color gauge fields in the length scale of the space-time sheet. The only interpretation consistent with quantum classical correspondence is in terms of a hierarchy of scaled up copies of standard model physics corresponding to p-adic length scale hierarchy and dark matter hierarchy labelled by arbitrarily large values of dynamical quantized Planck constant. Chirality selection in the bio-systems provides direct experimental evidences for this fractal hierarchy of standard model physics.

In the recent view the fluxes reduce at elementary particle level to gauge fluxes over wormhole throats at which induced Kähler form is self-dual so that Kähler-magnetic and -electric charges are identical and quantized. The quantal charges are assigned to string world sheets at which spinor modes are restricted in the generic casse by the well-definedness of em charge. Induced W fields vanish at them and above weak scale also induce Z^0 field.

3. There are some questions which looked highly non-trivial for years. Do vacuum charge densities give rise to renormalization effects or imply non-conservation so that weak charges would be screened above intermediate boson length scale? Could one assign the non-conservation of gauge fluxes to the wormhole (#) contacts, which are identifiable as pieces of CP_2 extremals and for which electro-weak gauge currents are not conserved so that weak gauge fluxes would be non-vanishing but more or less random so that long range correlations would be lost?

   After almost two decades after posing these questions it has become clear that vacuum currents are light-like for preferred extremals of Kähler action and that coupling constant evolution makes sense only at the GRT-QFT limit of TGD and seems to be p-adic coupling constant evolution with the p-adic length scale determined by the size scale of causal diamond (CD).

4. # (or wormhole-) contacts feeding gauge fluxes from a given sheet of the 3-space to a larger one are a necessary concomitant of the many-sheeted space-time concept. Their physical interpretation remained unclear for a long time.

   (a) # contacts can be regarded as particles carrying classical charges defined by the gauge fluxes but behaving as extremely tiny dipoles quantum mechanically in the case that gauge charge is conserved. # contacts must be light, which suggests that they can form Bose-Einstein condensates and coherent states. The real surprise (after 27 years of TGD) was that Higgs boson can be identified as a wormhole contact so that the generation of vacuum expectation value of Higgs field would correspond to a formation of coherent state of wormhole contacts with quantum numbers of Higgs particle.

   (b) It took some time to realize that all gauge bosons could be regarded as wormhole contacts and that fermions correspond naturally to wormhole throats of topologically condensed CP_2 type extremals. Graviton in turn would correspond to a pair of wormhole contacts connected by flux tubes so that stringlike object is in question. This picture follows unavoidably from the assumption that fermions are free at partonic level and leads to a detailed understanding of particle massivation at the level of first principles.

I have not discussed in this chapter the most recent developments in quantum TGD in detail except by references to the next chapter, where these developments are summarized.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://tgdtheory.fi/cmaphtml.html` [L3]. Pdf representation of same files serving as a kind of glossary can be found at `http://tgdtheory.fi/tgdglossary.pdf` [L4].

- Classical TGD [L2]
- Manysheeted space-time [L5]

2 What Do Space-Like 3-Surfaces Look Like?

This section provides a general picture of space-like 3-surfaces starting renormalization group invariance from spin glass analogy, the selection of preferred extremals of the Kähler action as generalized Bohr orbits, and from the special properties of the induced gauge fields implied by the compactness of CP_2.

This summary does not consider light-like 3-surfaces associated with wormhole throats and light-like boundaries of space-time sheets are much more suitable for the formulation of quantum TGD. In principle the two notions are dual to each other. Light-like 3-surfaces can be seen as a generalization of Feynman diagrams with lines represented by light-like 3-manifolds meeting along their 2-D ends representing vertices.

2.1 Renormalization Group Invariance, Quantum Criticality And Topology Of 3-Space

Renormalization group invariance, quantum criticality, and spin glass analogy are basic notions of quantum TGD but it is far from clear what these notions really mean at the level of space-time physics.

2.1.1 What quantum criticality means?

RGI (Renormalization group invariance) hypothesis states essentially that TGD Universe is quantum critical meaning that quantum theory is mathematically equivalent with a statistical system at critical point. S-matrix elements are analogous to thermal averages of observables, α_K corresponds to critical temperature and the vacuum functional $exp(K)$ corresponds to $exp(-H/T)$. The physical interpretation of the Kähler function suggests that $\alpha_K(phys)$ might correspond to a critical temperature at which spontaneous Kähler magnetization and formation Kähler electric fields compete.

RGI actually has actually rather concrete meaning: Kähler action contains no coupling constants so that it is not possible to speak about coupling constants and coupling constant evolution at the level of many-sheeted space-time. Coupling constant evolution emerges only as discrete p-adic coupling constant evolution at the level of effective space-time obtained by replacing the many-sheeted space-time with M^4 and endowed with effective metric whose deviation form M^4 metric is sum of the deviations of the induced metrics of space-time sheets from M^4 metric. Gauge potentials are defined in the same manner. This defines the counterpart of GRT space-time carrying standard model gauge fields and particles. Therefore the situation would be much like that what it is in say $\mathcal{N} = 4$ SUSY and the complexities of coupling constant evolution emerges when when throws out the topologogy of many-sheeted space-time.

The analogy with spin glass phase in four-dimensional sense is an additional characteristics feature. This allows the critical value of the α_K to depend on the zero modes of the WCW metric.

The naive idealized interpretation for the quantum criticality would be that 3-surfaces with all possible sizes contribute to the functional integral. In realistic situations there is some upper bound for the size and duration quantum fluctuations and the size of the largest space-time sheet involved would define the scales in question.

Spin glass analogy leads to the idea that WCW decomposes into regions D_p characterized by the p-adic prime p such that one can associate a hierarchy of p-adic length scales $L_p(n) = \sqrt{p}^{n-1}l$, $l \sim 10^4\sqrt{G}$ to each value of p [K17]. The critical value of α_K can in principle depend on p but the recent view is that α_K and perhaps also gravitational constant are invariant under p-adic coupling constant evolution. p-Adic length scales scales define natural upper bounds for the scale of quantum fluctuations associated with the quantum critical space-time sheet. Dark matter hierarchy in turn assigns to each p-adic length scale a hierarchy of further length scales scaled up by the values of $\hbar/\hbar_0$. The typical duration of quantum fluctuation would correspond to the typical geometric duration of maximal deterministic region inside space-time sheet.

2.1.2 The notion of preferred extremal

The first question is what preferred extremal could mean.

1. In positive energy ontology preferred extremal would be a space-time surface assignable to given 3-surface and unique in the ideal situation: since one cannot pose conditions to the normal derivatives of imbedding space coordinates at 3-surface, there is infinity of extremals. Some additional conditions are required and space-time surface would be analogous to Bohr orbit: hence the attribute "preferred". The problem would be to understand what "preferred"

could mean. The non-determinism of Kähler action however destroyed this dream in its original form and led to zero energy ontology (ZEO).

2. In ZEO one considers extremals as space-time surfaces connecting two space-like 3-surfaces at the boundaries. One might hope that these 4-surfaces are unique. The non-determinism of Kähler action suggests that this is not the case. At least there is conformal invariance respecting the light-likeness of the 3-D parton orbits at which the signature of the induced metric changes: the conformal transformations would leave the space-like 3-D ends or at least partonic 2-surfaces invariant. This non-determinism would correspond to quantum criticality.

3. Effective 2-dimensionality follows from strong form of general coordinate invariance (GCI) stating that light-like partonic orbits and space-like 3-surfaces at the ends of space-time surface are equivalent physically: partonic 2-surfaces and their 4-D tangent space data would determine everything. One can however worry about how effective 2-dimensionality relates to the the fact that the modes of the induced spinor field are localized at string world sheets and partonic 2-surface. Are the tangent space data equivalent with the data characterizing string world sheets as surfaces carrying vanishing electroweak fields?

   There is however a problem: the hierarchy of Planck constants (dark matter) requires that the conformal equivalence classes of light-like surfaces must be counted as physical degrees of freedom so that either space-like or light-like surfaces do not seem to be quite enough.

   Should one then include also the light-like partonic orbits to the what one calls 3-surface? The resulting connected 3-surfaces would define analogs of Wilson loops. Could the conformal equivalence class of the preferred extremal be unique without any additional conditions? If so, one could get rid of the attribute "preferred". The fractal character of the many-sheeted space-time however suggests that one can have this kind of uniqueness only in given length scale resolution and that "radiative corrections" due to the non-determinism are always present.

These considerations show that the notion of preferred extremal is still far from being precisely defined and it is not even clear whether the attribute "preferred" is needed. If not then the question is what are the extremals of Kähler action.

2.1.3 What are the competing phases?

Quite generally, critical systems are characterized by long range correlations (correlation length ξ diverges) for the competing phases present in the system. Physically this means the coexistence of arbitrarily large volumes of the two phases. Both Kähler magnetized 3-surfaces and 3-surfaces containing predominantly Kähler electric fields contribute significantly to the functional integral are present. At the infinite volume limit the Kähler action per volume must vanish since otherwise the vacuum functional vanishes: TGD cosmology [K20] is in accordance with this picture.

The problem of identifying the extremals (preferred at least in positive energy ontology) of Kähler action has been one of the most longstanding challenges of TGD. The solution of the problem came via the formulation of WCW geometry from the notion of number theoretical compactification [K25] in terms of second quantized induced spinor field at light-like 3-surfaces [K28]. The original hypothesis was that preferred extremals correspond to absolute minima of Kähler action: this might be true for Euclidian space-time regions.

The recent formulation in terms of boundary conditions at light-like surfaces is consistent with what is known about extremals of Kähler action [K4]. This formulation does not exclude absolute minimization or some variant of it. Note however that for the absolute minimization of Kähler action Kähler electric fields dominate and it is not clear whether there are solutions for which the Kähler action of the entire Universe is finite.

The notion of absolute minimization possibly making sense in Euclidian regions (enough for Kähler function since Minkowskian regions give imaginary contribution to the exponent of vacuum functional and define analog of Morse function) does not make sense in p-adic context unless one manages to reduce it to purely algebraic conditions. Therefore it is better to talk just about preferred extremals of Kähler action and accept as the fact that there are several proposals for what this notion could mean. For instance, one can consider the identification of space-time surface as quaternionic sub-manifold meaning that tangent space of space-time surface can be regarded as quaternionic sub-manifold of complexified octonions defining tangent space of imbedding space. One manner to define “quaternionic sub-manifold” is by introducing octonionic representation of imbedding space gamma matrices identified as tangent space vectors. It must be also assumed that the tangent space contains a preferred complex (commutative) sub-space at each point and defining an integrable distribution having identification as string world sheet (also slicing of space-time sheet by string world sheets can be considered). Associativity and commutativity would define the basic dynamical principle. A closely related approach is based on so called Hamilton-Jacobi structure [K4] defining also this kind of slicing and the approaches could be equivalent. A further approach is based on the identification of preferred extremal property as quantum criticality [K4].

2.1.4 How quantum fluctuations and thermal fluctuations relate to each other?

An experimental fact is that quantum critical systems such as high temperature superconductors [K6, K7] exist in a rather narrow parameter range, and one can say that quantum criticality becomes visible only when quantum fluctuations are not masked by thermal fluctuations. One should express this fact using TGD based notions.

p-Adic and dark matter hierarchies correspond also to hierarchies for quantum jumps with time scales given the average geometric duration for quantum jump. This hierarchy means quantum parallel dissipation about which hadrons as quantum systems containing quarks as dissipating subsystem at shorter p-adic length and time scale give a basic example.

At given space-time sheet short scale thermal fluctuations would have interpretation as quantum parallel fluctuations at smaller space-time sheets topologically condensed to the space-time sheet in question whereas the quantum critical fluctuations would correspond to the quantum fluctuations in the scale of the space-time sheet. The duration of maximal deterministic space-time region would correspond to the duration of single quantum state in the sequence of quantum jumps. The interpretation would be that only at quantum criticality the quantal fluctuations in long time scales can mask the thermal fluctuations in shorter scales.

2.1.5 How does quantum measurement theory relate to quantum criticality?

A further question is how quantum measurement theory relates to this picture. WCW zero modes represent non-quantum fluctuating classical observables correlating with quantum numbers and in quantum measurement a localization in zero modes occurs. Does this mean that the localization in zero modes breaks quantum criticality above the time scale corresponding to the typical geometric time duration of quantum jump by selecting precise values of zero modes?

2.1.6 Formation of join along boundaries/flux tube condensates and visible-to-dark phase transitions as mechanisms giving rise to quantum critical systems

The phase transition from visible to dark matter, and more generally, the transitions increasing the value of Planck constant define the first mechanism leading to the formation of larger quantum critical system and long range quantum fluctuations can be assigned to dark matter.

The formation of a join along boundaries/flux tube condensate means also a formation of a quantum critical system. The 3-surfaces with a typical size of order L_p combine together by flux tubes to form larger surfaces. Above criticality there are no bonds, below criticality all 3-surfaces combine to form larger condensates and at criticality there are join along boundaries/flux tube condensates with all possible sizes up to the cutoff length scale (see **Fig. 1**). Note that, at least for small values of p, the surfaces with typical sizes $\sqrt{p}^n L_p$, $n = ..0, 1, 2, ...$ correspond to the presence of all surface sizes related by a fractal scaling for a given p. A more precise formulation for what the fusion of p-adic and real [H2] [K25] means supports the view that topological field quanta allow a discrete scaling symmetry identifiable as scalings by powers of $\sqrt{p}$.

2.2 3-Surfaces Can Have Outer Boundaries

In length scales larger than hadronic length scale 3-surface with size L means roughly a condensate of smaller scale 3-surfaces on a piece of Minkowski space of size L. It is quite essential that these surfaces have finite size and therefore have outer boundary. The finite size of the 3-surfaces follows

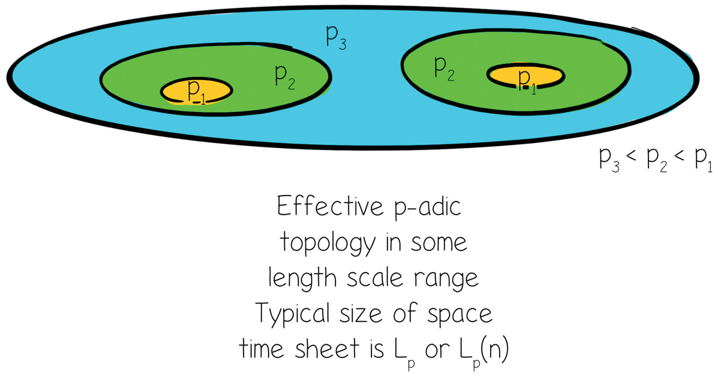

Figure 1: Hierarchical, fractal like structure of topological condensate predicted by RGI hypothesis: 2-dim. visualization

from the minimization of the Kähler action and from the compactness of CP_2. The argument goes as follows.

The matter inside a 3-surface creates gauge fields. In particular, the minimization of the absolute value of Kähler action in a region with definite sign of action density implies that matter serves as a source of either Kähler magnetic or Kähler electric fields. For instance, the Kähler electric field created by a constant mass distribution increases without bound. The smooth imbeddings of the gauge fields are however not possible globally and space-time decomposes into topological field quanta and their boundaries correspond to edges of space time. The elimination of the edges leads to a 3-space consisting of disjoint components. Simple examples are provided by a cylindrically symmetric imbedding of a constant magnetic field and the Kähler electric field created by a constant mass distribution, which fail for certain critical radii.

One can understand at general level how the compactness of CP_2 enters into the game. The point is that the gauge potentials associated with the induced gauge fields are bounded functions of CP_2 coordinates. For instance, for a geodesic sphere S^2 of CP_2 gauge potentials are just proportional to $A = sin(\Theta)d\Phi$. For a generic gauge field the gauge potential is not bounded (as an example consider gauge potentials of the Coulomb field or Kähler electric field created by a constant charge distribution or by a constant magnetic field). Therefore for certain values of CP_2 coordinates the representation of the gauge potential as an induced gauge potential fails. The failure takes place at some 3-surface of X^4. One can continue the embedding by changing the values of vacuum quantum numbers but certain CP_2 coordinates possess discontinuous or even infinite derivatives on the boundary so that undesirable edges of space time result. The manner to get rid of edges is to allow boundary for X^3 so that a region, where the the representation of the gauge potential as induced gauge potential works defines a natural unit of space-time, which might be called topological field quantum. In the sequel this phenomenon will be considered in more detail.

An obvious question is what happens to the gauge fluxes of long range gauge fields near the boundaries of the topological field quantum. Same question applies also to the gravitational flux associated with the Newtonian potential at the non-relativistic limit. One possibility is the appearance of neutralizing vacuum gauge charges and negative gravitational masses near the boundaries of the field quantum, perhaps related to vacuum polarization: this alternative must be realized for the particles of vapor phase. Second possibility is topological condensation on a larger topological field quantum so that gauge and gravitational fluxes flow to the larger topological field quantum via # contacts. The larger field quantum in turn must feed its gauge fluxes in a similar manner to larger field quantum so that the hierarchical structure of topological condensate is implied by the compactness of CP_2 and gauge flux conservation. Criticality implies only that 3-surfaces of arbitrarily large size are possible and therefore the number of the condensate levels and corresponding length scales $L(n)$ is infinite. Without criticality there would be some upper bound for 3-surfaces and only vapor phase would be possible.

The # contacts feeding the gauge fluxes from level p_n to level p_{n+1} are located near the boundaries of topological field quanta: otherwise long range gauge fields would not be possible inside the topological field quanta. A more quantitative hypothesis is that # contacts are located in the boundary layer having thickness of order L_{p_n}. If topological field quantum at level n has the minimum size of order L_{p_n} then the # contacts neutralize the physical gauge charges on the average.

A natural identification for wormhole contacts is as slightly deformed pieces of CP_2 type vacuum extremals having Euclidian signature of induced metric. Wormhole throats are identified as 3-surfaces at which the signature of induced metric changes and are therefore light-like 3-surfaces. The realization that these surfaces are ideal for the formulation of quantum TGD meant breakthrough in the construction of quantum TGD. The interpretation of the wormhole contacts as elementary bosons was crucial for understanding boson massivation and Higgs mechanism [K14].

2.3 Topological Field Quantization

Topological field quantization is a very general phenomenon differentiating between the TGD based and Maxwellian field concepts and results from the compactness of CP_2 only, being independent of any dynamical assumptions.

Topological field quantization occurs for surfaces representable as maps from M^4 to CP_2 and means that space time surface decomposes into regions characterized by certain vacuum quantum numbers characterizing the dependence of the phase angles Ψ and Φ associated with the two complex coordinates ξ_1 and ξ_2 of CP_2. There are two frequency type vacuum quantum numbers ω_1 and ω_2 characterizing the time dependence, two wave vector like quantum numbers k_1, k_2 characterizing the z-dependence and two integer valued vacuum quantum numbers n_1, n_2 characterizing the angle dependence of these phase angles. Topological field quantization fixes unique M^4 and CP_2 coordinates inside the field quantum and is analogous to a choice of a quantization axis.

2.3.1 Topological field quanta

Before considering the general form of the surfaces representable as maps $M^4 \to CP_2$ some comments about CP_2 coordinates are needed:

1. The so called Eguchi-Hanson coordinates for CP_2 are given $(r, u, \Psi, \Phi) \in [0, \infty] \times [-1, 1] \times [0, 4\pi] \times [0, 2\pi]$ (see Appendix [L1], [L1]). Ψ and and Φ are angle like coordinates closely related to the phases of the two complex coordinates of CP_2 and are the interesting variables in the sequel.

2. There are following types of coordinate singularities.

   (a) For $r = 0$ all values of Ψ and Φ correspond to same point of CP_2.

   (b) For $r = \infty$ all values of Ψ correspond to same point of CP_2. For $u = 1$ and $u = -1$ also all values of Φ correspond to same point of CP_2.

Consider now the space-time surface representable as a graph of a map $M^4 \to CP_2$. The general form of the angle coordinates Ψ and Φ as functions of M^4 cylindrical coordinates (t, z, ρ, ϕ) is given by the expression

$$\begin{aligned} \Phi &= \omega_1 t + k_1 z + n_1 \phi + \text{Fourier expansion} \ , \\ \Psi &= \omega_2 t + k_2 z + n_2 \phi + \text{Fourier expansion} \ . \end{aligned} \tag{2.1}$$

There always exists a rest frame, where k_1 or k_2 vanishes. The Fourier expansion is single valued in ϕ and finite in z and t. The vacuum quantum numbers ω_1 and ω_2 are frequency type vacuum quantum numbers to be referred as "electric" quantum numbers. The quantum numbers (n_1, n_2) are integer valued and will be referred to as "magnetic" quantum numbers.

The values of the vacuum quantum numbers can change at the boundaries of the regions of space-time determined by the conditions
i) $r = 0$ and $(r = \infty, u = \pm 1)$: here all vacuum quantum numbers can change
ii) $r = \infty$: here only ω_2, n_2 and k_2 can change.
Also the choice of CP_2 coordinates and M^4 coordinates can in principle change: different CP_2 coordinates are related by color rotation and different M^4 coordinates by Lorentz transformation.

In general, the boundaries of the regions correspond to edges of space-time in the sense that CP_2 coordinates possess discontinuous or infinite derivatives at the boundaries of the field quanta. A natural manner to get rid of the edges is to consider 3- surfaces consisting of a single region only so that single region of this kind, topological field quantum, is a natural unit of 3-space. There is however an important exception to this. The join along boundaries interaction (or its flux tube counterpart) very probably means the gluing of two topological field quanta together along their boundaries and provides a manner to construct coherent quantum systems from smaller units.

The sizes of the topological field quanta are indeed finite so that the boundary of 3-space (quite essential for the ideas described before) is an unavoidable consequence of the compactness of CP_2 and the minimization of the Kähler action. The dependence of the size of the 3-surface on the vacuum quantum numbers is in accordance with the proposed interpretation: at the limit of large vacuum quantum numbers the size of the topological field quantum becomes macroscopic and at small vacuum quantum number limit the size of the surface becomes small.

Very complicated hierarchical structures predicted by the RGI are in principle possible since topological field quanta can suffer topological condensation on larger field quanta. Field quanta can become nested and both spatial and temporal structures (nesting in time like direction) are possible.

2.3.2 The vacuum quantum numbers associated with vacuum extremals

Vacuum extremals define a reasonable starting point for TGD based model for gravitational interactions. For vacuum extremals classical em and Z^0 fields are proportional to each other (see the Appendix of the book):

$$\begin{aligned} Z^0 &= 2e^0 \wedge e^3 = \frac{r}{F^2}(k+u)\frac{\partial r}{\partial u} du \wedge d\Phi = (k+u) du \wedge d\Phi \ , \\ r &= \sqrt{\frac{X}{1-X}} \ , \ X = D|k+u| \ , \\ \gamma &= -\frac{p}{2} Z^0 \ . \end{aligned} \tag{2.2}$$

For a vanishing value of Weinberg angle ($p = sin^2(\theta_w) = 0$) em field vanishes and only Z^0 field remains as a long range gauge field.

The study of the imbeddings of the Schwartshild metric as vacuum extremals (gravitational mass is non-vanishing but inertial mass vanishes) shows that astrophysical length scales correspond to large vacuum quantum number limit of TGD. Any mass vacuum extremal is necessarily accompanied by long ranged electro-weak and color fields and from the requirement that the corresponding force is weaker than the gravitational force one obtains that the value of the parameter ω_1 is of the order of $1/R \sim 10^{-4}\sqrt{G}$.

A simple example about the decomposition of space-time into topological field quanta is obtained by considering the cylindrically symmetric imbedding of a constant magnetic field in the z-direction as a vacuum extremal. Electromagnetic field can be written as $F^{em}_{\rho\phi} = B_0 \rho$ and using the general results from the Appendix of the book one can write

$$\begin{aligned} u = u(\rho) \ , \quad & \Phi = n_1 \phi \ , \\ r = \sqrt{\tfrac{X}{1-X}} \ , \quad & X = D|k+u| \ , \\ A^{em}_{\phi} = \frac{B_0 \rho^2}{2} &= -\frac{p}{2} n_1 (k+u) \partial_\rho u \ . \end{aligned} \tag{2.3}$$

Assuming that $(r, u) = (0, 0)$ holds true at z-axis, the equation for em gauge potential A^{em} fixes the relationship between ρ and u as

$$u = -k \pm \sqrt{k^2 - \frac{2B_0\rho^3}{3n_1p}} \ . \qquad (2.4)$$

The finite value range $0 \leq u \leq 1$ implies that the imbedding fails for certain values of ρ. Also the requirement that u is real implies an upper bound for ρ: the larger the value of n_1 the larger the critical radius. Imbedding can fail also for $X < 0$ and $X > 1$ corresponding to critical values of u equal $u_0 = -k$ and $D|(k + u_1)| = 1$.

2.4 Comparison Of Maxwellian And TGD Views About Classical Gauge Fields

In TGD Universe gauge fields are replaced with topological field quanta. Examples are topological light rays, magnetic flux tubes and sheets, and electric flux quanta carrying both magnetic and electric fields. Flux quanta form a fractal hierarchy in the sense that there are flux quanta inside flux quanta. It is natural to assume quantization of Kähler magnetic flux. Braiding and reconnection are basic topological operations for flux quanta.

One important example is the description of non-perturbative aspects of strong interactions in terms of reconnection of color magnetic flux quanta carrying magnetic monopole fluxes [K12, K15]. These objects are string like structures and one can indeed assign to them string world sheets. The transitions in which the thickness of flux tube increases so that flux conservation implies that part of magnetic energy is liberated unless the length of the flux quantum increases, are central in TGD inspired cosmology and astrophysics. The magnetic energy of flux quantum is interpreted as dark energy and magnetic tension as negative "pressure" causing accelerated expansion.

This picture is beautiful and extremely general but raises challenges. How to describe interference and linear superposition for classical gauge fields in terms of topologically quantized classical fields? How the interference and superposition of Maxwellian magnetic fields is realized in the situation when magnetic fields decompose to flux quanta? How to describe simple systems such as solenoidal current generating constant magnetic field using the language of flux quanta?

2.4.1 Superposition of fields in terms of flux quanta

The basic question concerns the elegant description of superposition of classical fields in terms of topological field quanta. What it means that magnetic fields superpose.

1. In Maxwell's linear theory the answer would be trivial but not now. Linear superposition holds true only inside topological light rays for signals propagating in fixed direction with light velocity and with same local polarization. The easy solution would be to say that one considers small perturbations of background space-time sheet and linearizes the theory. Linearization would apply also to induced gauge fields and metric and one would obtain linear superposition approximately. This does not look elegant. Rather, quantum classical correspondence requires the space-time counterpart for the expansion of quantum fields as sum of modes in terms of topological field quanta. Topological field quanta should not lose their identity in the superposition.

2. In the spirit of topological field quantization it would be nice to have topological representation for the superposition and interference without any linearization. To make progress one must return to the roots and ask how the fields are operationally defined. One has test particle and it experiences a gauge force in the field. From the acceleration of the test particle the value of field is deduced. What one observes is the superposition of gauge forces, not of gauge fields.

   (a) Let us just assume that we have two space-time sheets representing field configurations to be effectively superposed. Suppose that they are "on top" of each other with respect to CP_2 degrees of freedom so that their M^4 volumes overlap. The points of the sheets representing the field values that would sum in Maxwell's theory are typically at distance of CP_2 radius of about 10^4 Planck lengths. Wormhole contacts representing he interaction between the field configurations are formed. Hence the analog of linear superposition does not hold true exactly. For instance, amplitude modulation becomes possible. This is however not essential for the argument.

(b) Test particle could be taken to be fermion which is simultaneously topologically condensed to both sheets. In other words, fermionic CP_2 type almost vacuum extremal touches both sheets and wormhole throats at which the signature of the induced metric changes is formed. Fermion experiences the sum of gauge forces from the two space-time sheets through its wormhole throats. From this one usually concludes that superposition holds true for the induced gauge fields. This assumption is however not true and is also un-necessary in the recent case. In case of topological light rays the representation of modes in given direction in terms of massless extremals makes possible to realize the analogy for the representation of quantum field as sum of modes. The representation does not depend on approximate linearity as in the case of quantum field theories and therefore removes a lot of fuzziness related to the quantum theory. In TGD framework the bosonic action is indeed extremely non-linear (see **Fig.** `http://tgdtheory.fi/appfigures/fieldsuperpose.jpg` or **Fig.** 11 in the appendix of this book).

3. This view about linear superposition has interesting implications. In effective superposition the superposed field patterns do not lose their identity which means that the information about the sources is not lost - this is true at least mathematically. This is nothing but quantum classical correspondence: it is the decomposition of radiation into quanta which allows to conclude that the radiation arrives from a particular astrophysical object. It is also possible to have superposition of fields to zero field in Maxwellian sense but in the sense of TGD both fields patterns still exist. Linear superposition in TGD sense might allow testing using time dependent magnetic fields. In the critical situation in which the magnetic field created by AC current passes through zero, flux quanta have macroscopic size and the direction of the flux quantum changes to opposite.

2.4.2 The basic objection against TGD

The basic objection against TGD is that induced metrics for space-time surfaces in $M^4 \times CP_2$ form an extremely limited set in the space of all space-time metrics appearing in the path integral formulation of General Relativity. Even special metrics like the metric of a rotating black hole fail to be imbeddable as an induced metric. For instance, one can argue that TGD cannot reproduce the post-Newtonian approximation to General Relativity since it involves linear superposition of gravitational fields of massive objects. As a matter fact, Holger B. Nielsen- one of the very few colleagues who has shown interest in my work - made this objection for at least two decades ago in some conference and I remember vividly the discussion in which I tried to defend TGD with my poor English.

The objection generalizes also to induced gauge fields expressible solely in terms of CP_2 coordinates and their gradients. This argument is not so strong as one might think first since in standard model only classical electromagnetic field plays an important role.

1. Any electromagnetic gauge potential has in principle a local imbedding in some region. Preferred extremal property poses strong additional constraints and the linear superposition of massless modes possible in Maxwell's electrodynamics is not possible.

2. There are also global constraints leading to topological quantization playing a central role in the interpretation of TGD and leads to the notions of field body and magnetic body having non-trivial application even in non-perturbative hadron physics. For a very large class of preferred extremals space-time sheets decompose into regions having interpretation as geometric counterparts for massless quanta characterized by local polarization and momentum directions. Therefore it seems that TGD space-time is very quantal. Is it possible to obtain from TGD what we have used to call classical physics at all?

The imbeddability constraint has actually highly desirable implications in cosmology. The enormously tight constraints from imbeddability imply that imbeddable Robertson-Walker cosmologies with infinite duration are sub-critical so that the most pressing problem of General Relativity disappears. Critical and over-critical cosmologies are unique apart from a parameter characterizing their duration and critical cosmology replaces both inflationary cosmology and cosmology characterized by accelerating expansion. In inflationary theories the situation is just the opposite of this: one ends up with fine tuning of inflaton potential in order to obtain recent day cosmology.

Despite these and many other nice implications of the induced field concept and of sub-manifold gravity the basic question remains. Is the imbeddability condition too strong physically? What about linear superposition of fields which is exact for Maxwell's electrodynamics in vacuum and a good approximation central also in gauge theories. Can one obtain linear superposition in some sense?

1. Linear superposition for small deformations of gauge fields makes sense also in TGD but for space-time sheets the field variables would be the deformations of CP_2 coordinates which are scalar fields. One could use preferred complex coordinates determined about SU(3) rotation to do perturbation theory but the idea about perturbations of metric and gauge fields would be lost. This does not look promising. Could linear superposition for fields be replaced with something more general but physically equivalent?

2. This is indeed possible. The basic observation is utterly simple: what we know is that the *effects* of gauge fields superpose. The assumption that fields superpose is un-necessary! This is a highly non-trivial lesson in what operationalism means for theoreticians tending to take these kind of considerations as mere "philosophy".

3. The hypothesis is that the superposition of effects of gauge fields occurs when the M^4 projections of space-time sheets carrying gauge and gravitational fields intersect so that the sheets are extremely near to each other and can touch each other (CP_2 size is the relevant scale).

A more detailed formulation goes as follows.

1. One can introduce common M^4 coordinates for the space-time sheets. A test particle (or real particle) is identifiable as a wormhole contact and is therefore point-like in excellent approximation. In the intersection region for M^4 projections of space-time sheets the particle forms topological sum contacts with all the space-time sheets for which M^4 projections intersect.

2. The test particle experiences the sum of various gauge potentials of space-time sheets involved. For Maxwellian gauge fields linear superposition is obtained. For non-Abelian gauge fields gauge fields contain interaction terms between gauge potentials associated with different space-time sheets. Also the quantum generalization is obvious. The sum of the fields induces quantum transitions for states of individual space time sheets in some sense stationary in their internal gauge potentials.

3. The linear superposition applies also in the case of gravitation. The induced metric for each space-time sheet can be expressed as a sum of Minkowski metric and CP_2 part having interpretation as gravitational field. The natural hypothesis that in the above kind of situation the effective metric is sum of Minkowski metric with the sum of the CP_2 contributions from various sheets. The effective metric for the system is well-defined and one can calculate a curvature tensor for it among other things and it contains naturally the interaction terms between different space-time sheets. At the Newtonian limit one obtains linear superposition of gravitational potentials. One can also postulate that test particles moving along geodesics in the effective metric. These geodesics are not geodesics in the metrics of the space-time sheets.

4. This picture makes it possible to interpret classical physics as the physics based on effective gauge and gravitational fields and applying in the regions where there are many space-time sheets which M^4 intersections are non-empty. The loss of quantum coherence would be due to the effective superposition of very many modes having random phases.

The effective superposition of the CP_2 parts of the induced metrics gives rise to an effective metric which is not in general imbeddable to $M^4 \times CP_2$. Therefore many-sheeted space-time makes possible a rather wide repertoire of 4-metrics realized as effective metrics as one might have expected and the basic objection can be circumvented In asymptotic regions where one can expect single sheetedness, only a rather narrow repertoire of "archetypal" field patterns of gauge fields and gravitational fields defined by topological field quanta is possible.

The skeptic can argue that this still need not make possible the imbedding of a rotating black hole metric as induced metric in any physically natural manner. This might be the case but need of course not be a catastrophe. We do not really know whether rotating blackhole metric is realized in Nature. I have indeed proposed that TGD predicts new physics new physics in rotating systems. Unfortunately, gravity probe B could not check whether this new physics is there since it was located at equator where the new effects vanish.

2.4.3 Time varying magnetic fields described in terms of flux quanta

An interesting challenge to describe time dependent fields in terms of topological field quanta which are in many respects static structures (for instance, flux is constant). The magnetic fields created by time dependent currents serves as a good example from which one can generalize. In the simplest situation the magnetic field strength experiences time dependent scaling. How to describe this scaling?

Consider first the scaling of the magnetic field strength in flux tube quantization.

1. Intuitively it seems clear that the field decomposes into flux quanta, whose M^4 projections can partially overlap. To get a connection to Maxwell's theory one can assume that the average field intensity is defined in terms of the flux of the magnetic field over a surface with area S. For simplicity consider constant magnetic field so that one has $B_{ave}S = \Phi = n\Phi_0$, where Φ_0 is the quantized flux for a flux tube assumed to have minimum value Φ_0. Integer n is proportional to the average magnetic field B_{ave}. B_{ave} must be reasonably near to the typical local value of the magnetic field which manifest itself quantum mechanically as cyclotron frequency.

2. What happens in the scaling $B \rightarrow B/x$. If the transversal area of flux quantum is scaled up by x the flux quantum is conserved. To get the total flux correctly, the number of flux quanta must scale down: $n \rightarrow n/x$. One indeed has $(n/x) \times xS = nS$. This implies that the total area associated with flux quanta within total area S is preserved in the scaling.

3. The condition that the flux is exact integer multiple of Φ_0 would pose additional conditions leading to the quantization of magnetic flux if the total area can be regarded as fixed. This need not to be true.

Consider as the first example slowly varying magnetic field created by an alternating running in current in cylindrical solenoid. There are flux tubes inside the cylindrical solenoid and return flux tubes outside it flowing in opposite direction. Flux tubes get thicker as magnetic field weakens and shift from the interior of solenoid outside. For some value x of the time dependent scaling $B \rightarrow B/x$ the elementary flux quantum Φ_0 reaches the radius of the solenoid. Quantum effects must become important and make possible the change of the sign of the elementary flux quantum. Perhaps quantum jump turning the flux quantum around takes place. After this the size of the flux quantum begins to decrease as the magnitude of the magnetic field increases. At the maximum value the size of the flux quantum is minimum.

This example generalizes to the magnetic field created by a linear alternating current. In this case flux quanta are cylindrical flux sheets for which magnetic field strength and thickness oscillators with time. Also in this case the maximum transversal area to the system defines a critical situation in which there is just single flux sheet in the system carrying elementary flux. This flux quantum changes its sign as the sign of the current changes.

2.4.4 The notion of conscious hologram

In TGD inspired theory of consciousness the idea about living system as a conscious hologram [K5] is central. It is of course far from clear what this notion means. The notions of interference and superposition of fields are crucial for the description of the ordinary hologram. Therefore the proposed general description for the TGD counterpart for the superposition of fields is a natural starting point for the more precise formulation of the notion of conscious hologram.

1. Consider ordinary hologram first. Reference wave and reflected wave interfere and produce an interference pattern to which the substrate of the hologram reacts so that its absorption coefficient is affected. When the substrate is illuminated with the conjugate of the reference wave, the original reflected wave is generated. The modification of the absorption coefficient is assumed to be proportional to the modulus squared fro the sum of the reflected and reference waves. This implies that the wave reflected from the hologram is in good approximation identical with the original reflected wave.

2. Conscious hologram would be dynamical rather than static. It would be also quantal: the quantum transitions of particles in the fields defined by the hologram would be responsible for the realization of the interference pattern as a conscious experience. The previous considerations actually leave only this option since the interference of classical fields does not happen. Reference wave and reflected wave correspond now to any field configurations. The charged particles having wormhole contacts to the space-time sheets representing the field configurations experience the sum of the fields involved, and this induces quantum jumps between the quantum states associated with the situation in which only the reference wave is present.

   This would induce a conscious experience representing an interference pattern. The reference wave can also correspond to a flux tube of magnetic body carrying a static magnetic field and defining cyclotron states as stationary state. External time dependent magnetic field can replace reflected wave and induces cyclotron transitions. Also radiation fields represented by MEs can represent the reference wave and reflected wave. If there is need for the "reading" of the hologram it would correspond to the addition of a space-time sheet carrying fields which in good approximation have opposite sign and same magnitude as those in the sheet representing reference wave so that the effect on the charged particles reduces to that of the "reflected wave". This step might be un-necessary since already the formation of hologram would give rise to a conscious experience. The conscious holograms created when the hologram is created and when the conjugate of the reference wave is added give rise to two different conscious representations. This might have something to do with holistic and reductionistic views about the same situation.

3. One can imagine several realizations for the conscious hologram. It seems that the realization at the macroscopic level is essentially four-dimensional. By quantum holography it would reduce at microscopic level to a hologram realized at the 3-D light-like surfaces defining the surfaces at which the signature of induce metric changes (generalized Feynman diagrams having also macroscopic size - anyons [K18]) or space-like 3-surfaces at the ends of space-time sheets at the two light-like boundaries of CD. Strong form of holography implied by the strong form of general coordinate invariance requires that holograms correspond to collections of partonic 2-surfaces in given measurement resolution. This could be understood in the sense that the charged particles defining the substrate can be described mathematically in terms of the ends of the corresponding light-like 3-surfaces at the ends of CDs. The cyclotron transitions could be thought of as occurring for particles represent as partonic 2-surfaces topologically condensed at several space-time sheets.

One can imagine several applications in TGD inspired quantum biology.

1. One can develop a model for how certain aspects of sensory experience could be understood in terms of interference patterns for signals sent from the biological body to the magnetic body. The information about the relative position of the magnetic body and biological body would be coded by the interference patterns giving rise to conscious sensory percepts. This information would represent geometric qualia [K11] giving information about distances and angles basically. There would be a magnetic flux tube representing the analog of the reference wave and magnetic flux tube carrying the analog of reflected wave which could represent the effect of neural activity. When the signal changes with time, cyclotron transitions are induced and conscious percept is generated. In principle it there is no need not compensate for the reference wave although also this is possible.

2. The natural first guess is that EEG rhythms (and those for its fractal generalization) represent reference waves and that the frequencies in question are either harmonics of cyclotron frequencies or linear combinations of these and Josephson frequency assignable to cell membrane (and possibly its harmonics). The modulation of membrane potential would induce modulations of Josephson frequency and if large enough would generate nerve pulses. These modulations would define the counterpart of the reflected wave. The flux tubes representing unperturbed magnetic field would represent reference waves.

3. For instance, the motion of the biological body changes the signal at the space-time sheets carrying the signal and this generates cyclotron transitions giving rise to a conscious experience. Perhaps the sensation of having a body is based in this mechanism. The signals could emerge from directly from cells: it could be that this sensation corresponds to lower level selves rather than us. Second option is that nerve pulses to brain induce the signals sent to the our magnetic body.

4. The motion of biological body relative to biological body generates virtual sensory experience which could be responsible for the illusions like train illusion and the unpleasant sensory experience about falling down from cliff by just imagining it. OBEs could be also due to the virtual sensory experiences of the magnetic body. One interesting illusion results when one swims long time in windy sea. When one returns to the shore one has rather long lasting experience of being in sea. Magnetic body gradually learns to compensate the motion of sea so that the perception of the wavy motion is reduced. At the shore this compensation mechanism however continues to work. This mechanism represents an example of adaptation and could be a very general mechanism. Since also magnetic body uses metabolic energy, this mechanism could have justification in terms of metabolic economy.

   Also thinking as internal, silent speech might be assigned with magnetic body and would represent those aspects of the sensory experience of ordinary speech which involve quantum jumps at magnetic body. This speech would be internal speech since there would be no real sound signal or virtual sound signal from brain to cochlea.

5. Conscious hologram would make possible to represent phase information. This information is especially important for hearing. The mere power spectrum is not enough since it is same for speech and its time reversal. Cochlea performs an analysis of sounds to frequencies. It it is not easy to imagine how this process could preserve the phase information associated with the Fourier components. It is believed that both right and left cochlea are needed to abstract the phase difference between the signals arriving to right and left ear allowing to deduce the direction of the source neural mechanisms for this has been proposed but these mechanism are not enough in case of speech. Could there exists a separate holistic representation in which sound wave as a whole generates a single signal interfering with the reference wave at the magnetic body and in this manner represents as a conscious experience the phase?

6. Also the control and reference signals from the magnetic body to biological body could create time dependent interference patterns giving rise to neural response initiating motor actions and other responses. Basically the quantum interference should reduce the magnitude of membrane resting potentials so that nerve pulses would be generated and give rise to motor action. Similar mechanism would be at work at the level of sensory receptors - at least retina. The generation of nerve pulses would mean kind of emergency situation at the neuronal level. Frequency modulation of Josephson radiation would be the normal situation.

3 Basic Phenomenology Of Topological Condensation

The notions of topological condensate and p-adic length scale hierarchy are in a central role in TGD and for a long time it seemed that the physical interpretation of these notions is relatively straightforward. The evolution of number theoretical ideas however forced to suspect that the implications for physics might be much deeper and involve not only a solution to the mysteries of dark matter but also force to bring basic notions of TGD inspired theory of consciousness. At this moment the proper interpretation of the mathematical structures involving typically infinite hierarchies generalizing considerably the mathematical framework of standard physics is far from established so that it is better to represent just questions with some plausible looking answers.

3.1 Basic Concepts

It is good to discuss the basic notions before discussing the definition of gauge charges and gauge fluxes.

3.1.1 CP_2 type vacuum extremals

CP_2 type extremals behave like elementary particles (in particular, light-likeness of M^4 projection gives rise to Virasoro conditions). CP_2 type vacuum extremals have however vanishing four-momentum although they carry classical color charges. This raises the question how they can gain elementary particle quantum numbers.

In topological condensation of CP_2 type vacuum extremal a light-like causal horizon is created. Number theoretical considerations strongly suggest that the horizon carries elementary particle numbers and can be identified as a parton. The quantum numbers or parton would serve as sources of the classical gauge fields created by the causal horizon.

In topological evaporation CP_2 type vacuum extremal carrying only classical color charges is created. This would suggest that the scattering of CP_2 type vacuum extremals defines a topological quantum field theory resulting as a limit of quantum gravitation (CP_2 is gravitational instanton) and that CP_2 type extremals define the counterparts of vacuum lines appearing in the formulation of generalized Feynman diagrams.

3.1.2 # contacts as parton pairs

The earlier view about # contacts as passive mediators of classical gauge and gravitational fluxes is not quite correct. The basic modification is due to the fact that one can assign parton or parton pair to the # contact so that it becomes a particle like entity. This means that an entire p-adic hierarchy of new physics is predicted.

1. Formally # contact can be constructed by drilling small spherical holes S^2 in the 3-surfaces involved and connecting the spherical boundaries by a tube $S^2 \times D^1$. For instance, CP_2 type extremal can be glued to space-time sheet with Minkowskian signature or space-time sheets with Minkowskian signature can be connected by # contact having Euclidian signature of the induced metric. Also more general contacts are possible since S^2 can be replaced with a 2-surface of arbitrary genus and family replication phenomenon can be interpreted in terms of the genus.

   The # contact connecting two space-time sheets with Minkowskian signature of metric is accompanied by two "elementary particle horizons", which are light-like 3-surfaces at which the induced 4-metric becomes degenerate. Since these surfaces are causal horizons, it is not clear whether # contacts can mediate classical gauge interactions. If there is an electric gauge flux associated with elementary particle horizon it tends to be either infinite by the degeneracy of the induced metric. It is not clear whether boundary conditions allow to have finite gauge fluxes of electric type. A similar difficulty is encountered when one tries to assign gravitational flux to the # contact: in this case even the existence of flux in non-singular case is far from obvious. Hence the naive extrapolation of Newtonian picture might not be quite correct.

2. Number theoretical considerations suggests that the two light-like horizons associated with # contacts connecting space-time sheets act as dynamical units analogous to shock waves or light fronts carrying quantum numbers so that the identification as partons is natural. Quantum holography would suggest itself in the sense that the quantum numbers associated with causal horizons would determine the long range fields inside space-time sheets involved.

3. # contacts can be modelled in terms of CP_2 type extremals topologically condensed simultaneously to the two space-time sheets involved. The topological condensation of CP_2 type extremal creates only single parton and this encourages the interpretation as elementary

particle. The gauge currents for CP_2 type vacuum extremals have a vanishing covariant divergence so that there are no conserved charges besides Kähler charge. Hence electro-weak gauge charges are not conserved classically in the region between causal horizons whereas color gauge charges are. This could explain the vacuum screening of electro-weak charges at space-time level. This is required since for the known solutions of field equations other than CP_2 type extremals vacuum screening does not occur.

4. In the special case space-time sheets have opposite time orientations and the causal horizons carry opposite quantum numbers (with four-momentum included) the # contact would serve the passive role of flux mediator and one could assign to the contact generalized gauge fluxes as quantum numbers associated with the causal horizons. This is the case if the contact is created from vacuum in topological condensation so that the quantum numbers associated with the horizons define naturally generalized gauge fluxes. Kind of generalized quantum dipoles living in two space-times simultaneously would be in question. # contacts in the ground state for space-time sheets with opposite time orientation can be also seen as zero energy parton-antiparton pairs bound together by a piece of CP_2 type extremal.

5. When space-time sheets have same time orientation, the two-parton state associated with the # contact has non-vanishing energy and it is not clear whether it can be stable.

3.1.3 $\#_B$ contacts as bound parton pairs

Besides # contacts also flux tubes (JABs, $\#_B$ contacts) are possible. They can connect outer boundaries of space-time sheets or the boundaries of small holes associated with the interiors of two space-time sheets which can have Minkowskian signature of metric and can mediate classical gauge fluxes and are excellent candidates for mediators of gauge interactions between space-time sheet glued to a larger space-time sheet by topological sum contacts and join along boundaries contacts. The size scale of the causal horizons associated with parton pairs can be arbitrary whereas the size scale of # contacts is given by CP_2 radius.

Consider first the original vision about JABs. The original belief was that the existence of the holes for real space-time surfaces is a natural consequence of the induced gauge field concept: for sufficiently strong gauge fields the imbeddability of gauge field as an induced gauge field fails and hole in space-time appears as a consequence. The holes connected by $\#_B$ contacts obey field equations, and a good guess is that they are light-like 3-surfaces and carry parton quantum numbers. This would mean that both # and $\#_B$ contacts allow a fundamental description in terms of pair of partons.

Magnetic flux tubes provide a representative example of $\#_B$ contact. Instead of $\#_B$ contact also more descriptive terms such as join along boundaries bond (JAB), color bond, and magnetic flux tube are used. $\#_B$ contacts serve also as a space-time correlate for bound state formation and one can even consider the possibility that entanglement might have braiding of bonds defined by # contacts as a space-time correlate [K26].

It seems difficult to exclude flux tubes between between holes associated with the two space-time sheets at different levels of p-adic hierarchy. If these contacts are possible, a transfer of conserved gauge fluxes would be possible between the two space-time sheets and one could speak about interaction in conventional sense.

The most recent TGD view about JABs is different. The recent belief is that boundaries- and jus JABs- are not allowed by the boundary conditions: space-time sheets with boundary are replaced with their double covers. Furthermore, elementary particles and also larger systems correspond to space-time regions which as lines of generalized Feynman diagrams have Euclidian signature of the induced metric. This suggests that magnetic flux tubes as deformations of cosmic strings have Euclidian signature of metric too. This is quite possible and in the simplest situation would require that string world sheet has Euclidian signature of the induced metric. JABs in this sense would serve as correlates of quantum entanglement between system that they connect together.

Double cover property means that JABs identified as Kähler magnetic flux tubes have cross section, which are closed surfaces, and thus can carry quantized Kähler magnetic flux. These flux tubes would provide correlates for the magnetic fields known to exist in cosmological scales but no possible in standard cosmology due to the fact that needed currents should be coherent in long scales. For monopole fluxes no currents are needed.

3.1.4 Topological condensation and evaporation

Topological condensation corresponds to a formation of # or $\#_B$ contacts between space-time sheets. Topological evaporation means the splitting of # or $\#_B$ contacts. In the case of elementary particles the process changes almost nothing since the causal horizon carrying parton quantum numbers does not disappear. The evaporated CP_2 type vacuum extremal having interpretation as a gravitational instanton can carry only color quantum numbers.

As # contact splits partons are created at the two space-time sheets involved. This process can obviously generate from vacuum space-time sheets carrying particles with opposite signs of energies and other quantum numbers. Positive energy matter and negative energy anti-matter could be thus created by the formation of # contacts with zero net quantum numbers which then split to produce pair of positive and negative energy particles at different space-time sheets having opposite time orientations. This mechanism would allow a creation of positive energy matter and negative energy antimatter with an automatic separation of matter and antimatter at space-time sheets having different time orientation. This might resolve elegantly the puzzle posed by matter-antimatter asymmetry.

The creation of # contact leads to an appearance of radial gauge field in condensate and this seems to be impossible at the limit of infinitely large space-time sheet since it involves a radical instantaneous change in field line topology. The finite size of the space-time sheet can however resolve the difficulty.

If all quantum numbers of elementary particle are expressible as gauge fluxes, the quantum numbers of topologically evaporated particles should vanish. In the case of color quantum numbers and Poincare quantum numbers there is no obvious reason why this should be the case. Despite this the cancellation of the interior quantum numbers by those at boundaries or light-like causal determinants could occur and would conform with the effective 2-dimensionality stating that quantum states are characterized by partonic boundary states associated with causal determinants. This could be also seen as a holographic duality of interior and boundary degrees of freedom [K21].

3.2 Gauge Charges And Gauge Fluxes

The concepts of mass and gauge charge in TGD has been a source of a chronic headache. There are several questions waiting for a definite answer. How to define gauge charge? What is the microscopic physics behind the gauge charges necessarily accompanying long range gravitational fields? Are these gauge charges quantized in elementary particle level? Can one associate to elementary particles classical electro-weak gauge charges equal to its quantized value or are all electro-weak charges screened at intermediate boson length scale? Is the generation of the vacuum gauge charges, allowed in principle by the induced gauge field concept, possible in macroscopic length scales? What happens to the gauge charges in topological evaporation? Should Equivalence Principle be modified in order to understand the fact that Robertson-Walker metrics are inertial but not gravitational vacua.

3.2.1 How to define the notion of gauge charge?

In TGD gauge fields are not primary dynamical variables but induced from the spinor connection of CP_2. There are two manners to define gauge charges.

1. In purely group theoretical approach one can associate non-vanishing gauge charge to a 3-surface of finite size and quantization of the gauge charge follows automatically. This definition should work at Planck length scales, when particles are described as 3-surfaces of CP_2 size and classical space-time mediating long range interactions make no sense. Gauge interactions are mediated by gauge boson exchange, which in TGD has topological description in terms of CP_2 type vacuum extremals [K4].

2. Second definition of gauge charge is as a gauge flux over a closed surface. In this case quantization is not obvious nor perhaps even possible at classical level except perhaps for

Abelian charges. For a closed 3-surface gauge charge vanishes and one might well argue that this is the case for finite 3-surface with boundary since the boundary conditions might well generate gauge charge near the boundary cancelling the gauge charge created by particles condensed on 3-surface. This would mean that at low energies (photon wavelength large than size of the 3-surfaces) the 3-surfaces in vapor phase look like neutral particles. Only at high energies the evaporated particles would behave as ordinary elementary particles. Furthermore, particle leaves in topological evaporation its gauge charge in the condensate.

The alternative possibility that the long range $\frac{1}{r^2}$ gauge field associated with particle disappears in the evaporation, looks topologically impossible at the limit when larger space-time sheet has infinite size: only the simultaneous evaporation of opposite gauge charges might be possible in this manner at this limit. Topological evaporation provides a possible mechanism for the generation of vacuum gauge charges, which is one basic difference between TGD and standard gauge theories.

There is a strong temptation to draw a definite conclusion but it is better to be satisfied with a simplifying working hypothesis that gauge charges are in long length scales definable as gauge fluxes and vanish for macroscopic 3-surfaces of finite size in vapor phase. This would mean that the topological evaporation of say electron as an electromagnetically charged particle would not be possible except at CP_2 length scale: in the evaporation from secondary condensation level electron would leave its gauge charges in the condensate. Vapor phase particle still looks electromagnetically charged in length scales smaller than the size of the particle surface if the neutralizing charge density is near (or at) the boundary of the surface and gauge and gravitational interactions are mediated by the exchange of CP_2 type extremals.

3.2.2 In what sense could # contacts feed gauge fluxes?

One can associate with the # throats magnetic gauge charges $\pm Q_i$ defined as gauge flux running to or from the throat. The magnetic charges are of opposite sign and equal magnitude on the two space-time sheets involved. For Kähler form the value of magnetic flux is quantized and non-vanishing only if the the $t = constant$ section of causal horizon corresponds to a non-trivial homology equivalence class in CP_2 so that # contact can be regarded as a homological magnetic monopole. In this case # contacts can be regarded as extremely small magnetic dipoles formed by tightly bound # throats possessing opposite magnetic gauge charges. # contacts couple to the difference of the classical gauge fields associated with the two space-time sheets and matter-# contact and # contact-# contact interaction energies are in general non-vanishing.

Electric gauge fluxes through # throat evaluated at the light-like elementary particle horizon X_l^3 tend to be either zero or infinite. The reason is that without appropriate boundary conditions the normal component of electric $F^{tn}\sqrt{(g_4)}/g^2$ either diverges or is infinite since g^{tt} diverges by the effective three-dimensionality of the induced metric at X_l^3. In the gravitational case an additional difficulty is caused by the fact that it is not at all clear whether the notion of gravitational flux is well defined. It is however possible to assign gravitational mass to a given space-time sheets as will be found in the section about space-time description of charge renormalization.

The simplest conclusion would be that the notions of gauge and gravitational fluxes through # contacts do not make sense and that # contacts mediate interactions in a more subtle manner. For instance, for a space-time sheet topologically condensed at a larger space-time sheet the larger space-time sheet would characterize the basic coupling constants appearing in the S-matrix associated with the topologically condensed space-time sheets. In particular, the value of $\hbar$ would characterize the relation between the two space-time sheets. A stronger hypothesis would be that the value of $\hbar$ is coded partially by the Jones inclusion between the state spaces involved. The larger space-time sheet would correspond to dark matter from the point of view of smaller space-time sheet [K27, K10].

One can however try to find loopholes in the argument.

1. It might be possible to pose the finiteness of $F^{tn}\sqrt{g_4}/g^2$ as a boundary condition. The variation principle determining space-time surfaces implies that space-time surfaces are analogous to Bohr orbits so that there are also hopes that gauge fluxes are quantized.

2. Another way out of this difficulty could be based on the basic idea behind renormalization in TGD framework. Gauge coupling strengths are allowed to depend on space-time point so

that the gauge currents are conserved. Gauge coupling strengths $g^2/4\pi$ could become infinite at causal horizon. The infinite values of gauge couplings at causal horizons might be a TGD counterpart for the infinite values of bare gauge couplings in quantum field theories. There are however several objections against this idea. The values of coupling constants should depend on space-time sheet only so that the situation is not improved by this trick in CP_2 length scale. Dependence of g^2 on space-time point means also that in the general case the definition of gauge charge as gauge flux is lost so that gauge charges do not reduce to fluxes.

It seems that the notion of a finite electric gauge flux through the causal horizon need not make sense as such. Same applies to the notion of gravitational gauge flux. The notion of gauge flux seems however to have a natural quantal generalization. The creation of a # contact between two space-time sheets creates two causal horizons identifiable as partons and carrying conserved charges assignable with the states created using the fermionic oscillator operators associated with the second quantized induced spinor field. These charges must be of opposite sign so that electric gauge fluxes through causal horizons are replaced by quantal gauge charges. For opposite time orientations also four-momenta cancel each other. The particle states can of course transform by interactions with matter at the two-space-time sheets so that the resulting contact is not a zero energy state always.

This suggests that for gauge fluxes at the horizon are identifiable as opposite quantized gauge charges of the partons involved. If the the net gauge charges of # contact do not vanish, it can be said to possess net gauge charge and does not serve as a passive flux mediator anymore. The possibly screened classical gauge fields in the region faraway from the contact define the classical correlates for gauge fluxes. A similar treatment applies to gravitational flux in the case that the time orientations are opposite and gravitational flux is identifiable as gravitational mass at the causal horizon.

Internal consistency would mildly suggest that # contacts are possible only between space-time sheets of opposite time orientation so that gauge fluxes between space-time sheets of same time orientation would flow along $\#_B$ bonds.

3.2.3 Are the gauge fluxes through # and $\#_B$ contacts quantized?

There are good reasons (criticality of the Kähler action plus maximization of the Kähler function) to expect that the gauge fluxes through # (if well-defined) and $\#_B$ contacts are quantized. The most natural guess would be that the unit of electric electromagnetic flux for $\#_B$ contact is 1/3 since this makes it possible for the electromagnetic gauge flux of quarks to flow to larger space-time sheets. Anyons could however mean more general quantization rules [K26]. The quantization of electromagnetic gauge flux could serve as a unique experimental signature for # and $\#_B$ contacts and their currents. The contacts can carry also magnetic fluxes. In the case of $\#_B$ contacts the flux quantization would be dynamical and analogous to that appearing in super conductors.

3.2.4 Hierarchy of gauge and gravitational interactions

The observed elementary particles are identified as CP_2 type extremals topologically condensed at space-time sheets with Minkowski signature of induced metric with elementary particle horizon being responsible for the parton aspect. This suggests that at CP_2 length scale gauge and gravitational interactions correspond to the exchanges of CP_2 type extremals with light-like M^4 projection with branching of CP_2 type extremal serving as the basic vertex as discussed first in the earliest attempt to construct [K1] and years later in terms of generalized Feynman diagrams. The gravitational and gauge interactions between the partons assignable to the two causal horizons associated with # contact would be mediated by the # contact, which can be regarded as a gravitational instanton and the interaction with other particles at space-time sheets via classical gravitational fields.

Gauge fluxes flowing through the $\#_B$ contacts would mediate higher level gauge and interactions between space-time sheets rather than directly between CP_2 type extremals. The hierarchy of flux tubes defining string like objects strongly suggests a p-adic hierarchy of "strong gravities" with gravitational constant of order $G \sim L_p^2$, and these strong gravities might correspond to gravitational fluxes mediated by the flux tubes.

3.3 Can One Regard $\#$ *Resp.* $\#_B$ Contacts As Particles *Resp.* String Like Objects?

$\#$-contacts have obvious particle like aspects identifiable as either partons or parton pairs. $\#_B$ contacts in turn behave like string like objects. Using the terminology of M-theory, $\#_B$ contacts connecting the boundaries of space-time sheets could be also seen as string like objects connecting two branes. Again the ends holes at the ends of $\#_B$ contacts carry well defined gauge charges.

3.3.1 $\#$ contacts as particles and $\#_B$ contacts as string like objects?

The fact that $\#$ contacts correspond to parton pairs raises the hope that it is possible to apply p-adic thermodynamics to calculate the masses of $\#$ contact and perhaps even the masses of the partons. If this the case, one has an order of magnitude estimate for the first order contribution to the mass of the parton as $m \sim 1/L(p_i)$, $i = 1, 2$. It can of course happen that the first order contribution vanishes: in this case an additional factor $1/\sqrt{p_i}$ appears in the estimate and makes the mass extremely small.

For $\#$ contacts connecting space-time sheets with opposite time orientations the vanishing of the net four-momentum requires $p_1 = p_2$. According to the number theoretic considerations below it is possible to assign several p-adic primes to a given space-time sheet and the largest among them, call it p_{max}, determines the p-adic mass scale. The milder condition is that p_{max} is same for the two space-time sheets.

There are some motivations for the working hypothesis that $\#$ contacts and the ends of $\#_B$ contacts feeding the gauge fluxes to the lower condensate levels or vice versa tend to be located near the boundaries of space-time sheets. For gauge charges which are not screened by vacuum charges (em and color charges) the imbedding of the gauge fields created by the interior gauge charges becomes impossible near the boundaries and the only possible manner to satisfy boundary conditions is that gauge fluxes flow to the larger space-time sheet and space-time surface becomes a vacuum extremal of the Kähler action near the boundary.

For gauge bosons the density of boundary $\#_B$ contacts should be very small in length scales, where matter is essentially neutral. For gravitational $\#_B$ contacts the situation is different. One might well argue that there is some upper bound for the gravitational flux associated with single $\#$ or $\#_B$ contact (or equivalently the gravitational mass associated with causal horizon) given by Planck mass or CP_2 mass so that the number of gravitational contacts is proportional to the mass of the system.

3.3.2 Could $\#$ and $\#_B$ contacts form macroscopic quantum phases?

The description as $\#$ contact as a parton pair suggests that it is possible to assign to $\#$ contacts inertial mass, say of order $1/L(p)$, they should be describable using d'Alembert type equation for a scalar field. $\#$ contacts couple dynamically to the geometry of the space-time since the induced metric defines the d'Alembertian. There is a mass gap and hence $\#$ contacts could form a Bose-Einstein (BE) condensate to the ground state. If $\#$ contacts are located near the boundary of the space-time surface, the d'Alembert equation would be 3-dimensional. One can also ask whether $\#$ contacts define a particular form of dark matter having only gravitational interactions with the ordinary matter.

Also coherent states of $\#$ contacts are possible and as will be found, Higgs mechanism could be understood as a generation of coherent state of neutral Higgs particles identified as wormhole contacts (see **Fig.** `http://tgdtheory.fi/appfigures/wormholecontact.jpg` or **Fig.** 10 in the appendix of this book) having quantum numbers of left (right) handed fermion and right (left) handed anti-fermion.

Also the probability amplitudes for the positions of the ends of $\#_B$ contacts located at the boundary of the space-time sheet could be described using an order parameter satisfying d'Alembert equation with some mass parameter and whether the notion of Bose-Einstein condensate makes sense also now. The model for atomic nucleus assigns to the ends of the $\#_B$ contact realized as a color magnetic flux tube having at its ends quark and anti-quark with mass scale given by $k = 127$ (MeV scale) [K22].

3.4 TGD Based Description Of External Fields

The description of a system in external field provides a nontrivial challenge for TGD since the system corresponds now to a p-adic space-time sheet k_1 condensed on background 3-surface $k_2 > k_1$. The problem is to understand how external fields penetrate into the smaller space-time sheet and also how the gauge fluxes inside the smaller space-time sheet flow to the external space-time sheet. One should also understand how the penetrating magnetic or electric field manages to preserve its value (if it does so). A good example is provided by the description of system, such as atom or nucleus, in external magnetic or electric field. There are several mechanisms of field penetration:

3.4.1 Induction mechanism

In the case of induction fields are mediated from level k_1 to levels $k_2 \neq k_1$. The external field at given level k_1 acts on $\#$ and $\#_B$ throats (both accompanied by a pair of partons) connecting levels k_2 and k_1. The motion of $\#$ and $\#_B$ contacts, induced by the gauge and gravitational couplings of partons involved to classical gauge and gravitational fields, creates gauge currents serving as sources of classical gauge field at the space-time sheets involved. This mechanism involves "dark" partons not predicted by standard model.

A good example is provided by the rotation of charged # throats induced by a constant magnetic field, which in turn creates constant magnetic field inside a cylindrical condensate space-time sheet. A second example is the polarization of the charge density associated with the # throats in the external electric field, which in turn creates a constant electric field inside the smaller space-time sheet.

One can in principle formulate general field equations governing the penetration of a classical gauge field from a given condensate level to other levels. The simplified description is based on the introduction of series of fields associated with various condensate levels as analogs of H and B and D and E fields in the ordinary description of the external fields. The simplest assumption is that the fields are linearly related. A general conclusion is that due to the delicacies of the induced field concept, the fields on higher levels appear in the form of flux quanta and typically the field strengths at the higher condensate levels are stronger so that the penetration of field from lower levels to the higher ones means a decomposition into separate flux tubes.

The description of magnetization in terms of the effective field theory of Weiss introduces effective field H, which is un-physically strong: a possible explanation as a field consisting of flux quanta at higher condensate levels. A general order of magnitude estimate for field strength of magnetic flux quantum at condensate level k is as $1/L^2(k)$.

3.4.2 Penetration of magnetic fluxes via # contacts

At least magnetic gauge flux can flow from level p_1 to level p_2 via # contacts. These surfaces are of the form $X^2 \times D^1$, where X^2 is a closed 2-surface. The simplest topology for X^2 is that of sphere S^2. This leads to the first nontrivial result. If a nontrivial magnetic flux flows through the contact, it is quantized. The reason is that magnetic flux is necessarily over a closed surface.

The concept of induced gauge field implies that magnetic flux is nontrivial only if the surface X^2 is homologically nontrivial: CP_2 indeed allows homologically nontrivial sphere. Ordinary magnetic field can be decomposed into co-homologically trivial term plus a term proportional to Kähler form and the flux of ordinary magnetic field comes only from the part of the magnetic field proportional to the Kähler form and the magnetic flux is an integer multiple of some basic flux.

The proposed mechanism predicts that magnetic flux can change only in multiples of basic flux quantum. In super conductors this kind of behavior has been observed. Dipole magnetic fields can be transported via several # contacts: the minimum is one for ingoing and one for return flux so that magnetic dipoles are actual finite sized dipoles on the condensed surface. Also the transfer of magnetic dipole field of, say neutron inside nucleus, to lower condensate level leads to similar magnetic dipole structure on condensate level. For this mechanism the topological condensation of elementary particle, say charged lepton space-time sheet, would involve at least two # contacts and the magnetic moment is proportional to the distance between these contacts. The requirement that the magnetic dipole formed by the # contacts gives the magnetic moment of the particle gives an estimate for the distance d between # throats: by flux quantization the general order of magnitude is given by $d \sim \frac{\alpha_{em} 2\pi}{m}$.

3.4.3 Penetration of electric gauge fluxes via # contacts

For # contact for the opposite gauge charges of partons define the value of generalized gauge electric flux between the two space-time sheets. In this case it is also possible to interpret the partons as sources of the fields at the two space-time sheets. If the # contacts are near the boundary of the smaller space-time sheet the interpretation as a flow of gauge flux to a larger space-time sheet is perfectly sensible. The partons near the boundary can be also seen as generators of a gauge field compensating the gauge fluxes from interior.

The distance between partons can be much larger than p-adic cutoff length $L(k)$ and a proper spatial distribution guarantees homogeneity of the magnetic or electric field in the interior. The distances of the magnetic monopoles are however large in this kind of situation and it is an open problem whether this kind of mechanism is consistent with experimental facts.

An estimate for the electric gauge flux Q_{em} flowing through the # contact is obtained as $n \sim \frac{E}{QL(k)}$: $Q \sim EL^2(k)$, which is of same order of magnitude as electric gauge flux over surface of are $L^2(k)$. In magnetic case the estimate gives $Q_M \sim BL^2(k)$: the quantization of Q_M is consistent with homogeneity requirement only provided the condition $B > \frac{\Phi_0}{L^2(k)}$, where Φ_0 is elementary flux quantum, holds true. This means that flux quantization effects cannot be avoided in weak magnetic fields. The second consequence is that too weak magnetic field cannot penetrate at all to the condensed surface: this is certainly the case if the total magnetic flux is smaller than elementary flux quantum. A good example is provided by the penetration of magnetic field into cylindrical super conductor through the end of the cylinder. Unless the field is strong enough the penetrating magnetic field decomposes into vortex like flux tubes or does not penetrate at all.

The penetration of flux via dipoles formed by # contacts from level to a second level in the interior of condensed surface implies phenomena analogous to the generation of polarization (magnetization) in dielectric (magnetic) materials. The conventional description in terms of fields H, B, M and D, E, P has nice topological interpretation (which does not mean that the mechanism is actually at work in condensed matter length scales). Magnetization M (polarization P) can be regarded as the density of fictitious magnetic (electric) dipoles in the conventional theory: the proposed topological picture suggests that these quantities essentially as densities for # contact pairs. The densities of M and P are of opposite sign on the condensed surface and condensate. $B = H - M$ corresponds to the magnetic field at condensing surface level reduced by the density $-M$ of # contact dipoles in the interior. H denotes the external field at condensate level outside the condensing surface, M $(-M)$ is the magnetic field created by the # contact dipoles at condensate (condensed) level. Similar interpretation can be given for D, E, P fields. The penetrating field is homogenous only above length scales larger than the distance between # throats of dipoles: p-adic cutoff scale $L(k)$ gives natural upper bound for this distance: if this is the case and the density of the contacts is at least of order $n \sim \frac{1}{L^3(k)}$ the penetrating field can be said to be constant also inside the condensed surface.

In condensed matter systems the generation of ordinary polarization and magnetization fields might be related to the permanent # contacts of atomic surfaces with, say, $k = 139$ level. The field created by the neutral atom contains only dipole and higher multipoles components and therefore at least two # contacts per atom is necessary in gas phase, where flux tubes between atoms are absent. In the absence of external field these dipoles tend to have random directions. In external field # throats behave like opposite charges and their motion in external field generates dipole field. The expression of the polarization field is proportional to the density of these static dipole pairs in static limit. # contacts make possible the penetration of external field to atom, where it generates atomic transitions and leads to the emission of dipole type radiation field, which gives rise to the frequency dependent part of dielectric constant.

3.4.4 Penetration via $\#_B$ contacts

The field can also through $\#_B$ contacts through the boundary of the condensed surface or through the small holes in its interior. The quantization of electric charge quantization would reduce to the quantization of electric gauge flux in $\#_B$ contacts. If there are partons at the ends of contact they affect the gauge gauge flux.

The penetration via $\#_B$ contacts necessitates the existence of join along boundaries bonds starting from the boundary of the condensed system and ending to the boundary component of a hole in the background surface. The field flux flows simply along the 3-dimensional stripe $X^2 \times D^1$: since X^2 has boundary no flux quantization is necessary. This mechanism guarantees automatically the homogeneity of the penetrating field inside the condensed system.

An important application for the theory of external fields is provided by bio-systems in which the penetration of classical electromagnetic fields between different space-time sheets should play central role: what makes the situation so interesting is that the order parameter describing the $\#$ and $\#_B$ Bose-Einstein condensates carries also phase information besides the information about the strength of the normal component of the penetrating field.

3.5 Number Theoretical Considerations

Number theoretical considerations allow to develop more quantitative vision about the how p-adic length scale hypothesis relates to the ideas just described.

3.5.1 How to define the notion of elementary particle?

p-Adic length scale hierarchy forces to reconsider carefully also the notion of elementary particle. p-Adic mass calculations led to the idea that particle can be characterized uniquely by single p-adic prime characterizing its mass squared. It however turned out that the situation is probably not so simple.

The work with modelling dark matter suggests that particle could be characterized by a collection of p-adic primes to which one can assign weak, color, em, gravitational interactions, and possibly also other interactions. It would also seem that only the space-time sheets containing common primes in this collection can interact. This leads to the notions of relative and partial darkness. An entire hierarchy of weak and color physics such that weak bosons and gluons of given physics are characterized by a given p-adic prime p and also the fermions of this physics contain space-time sheet characterized by same p-adic prime, say M_{89} as in case of weak interactions. In this picture the decay widths of weak bosons do not pose limitations on the number of light particles if weak interactions for them are characterized by p-adic prime $p \neq M_{89}$. Same applies to color interactions.

The p-adic prime characterizing the mass of the particle would perhaps correspond to the largest p-adic prime associated with the particle. Graviton which corresponds to infinitely long ranged interactions, could correspond to the same p-adic prime or collection of them common to all particles. This might apply also to photons. Infinite range might mean that the flux tubes mediating these interactions can be arbitrarily long but their transversal sizes are characterized by the p-adic length scale in question.

The natural question is what this collection of p-adic primes characterizing particle means? The hint about the correct answer comes from the number theoretical vision, which suggests that at fundamental level the branching of boundary components or more generally wormhole throats to two or more components, completely analogous to the branching of line in Feynman diagram, defines vertices [K9, K8].

1. If space-time sheets correspond holographically to multi-p p-adic topology such that largest p determines the mass scale, the description of particle reactions in terms of branchings indeed makes sense. This picture allows also to understand the existence of different scaled up copies of QCD and weak physics. Multi-p p-adicity could number theoretically correspond to q-adic topology for $q = m/n$ a rational number consistent with p-adic topologies associated with prime factors of m and n ($1/p$-adic topology is homeomorphic with p-adic topology).

2. One could also imagine that different p-adic primes in the collection correspond to different space-time sheets condensed at a larger space-time sheet or boundary components of a given space-time sheet. If the boundary topologies for gauge bosons are completely mixed, as the model of hadrons forces to conclude, this picture is consistent with the topological explanation of the family replication phenomenon and the fact that only charged weak currents involve mixing of quark families. The problem is how to understand the existence of different copies of say QCD. The second difficult question is why the branching leads always to an emission of gauge boson characterized by a particular p-adic prime, say M_{89}, if this p-adic prime does not somehow characterize also the particle itself.

3.5.2 What effective p-adic topology really means?

The need to characterize elementary particle p-adically leads to the question what p-adic effective topology really means. p-Adic mass calculations leave actually a lot of room concerning the answer to this question.

1. The naivest option is that each space-time sheet corresponds to single p-adic prime. A more general possibility is that the boundary components of space-time sheet correspond to different p-adic primes. This view is not favored by the view that each particle corresponds to a collection of p-adic primes each characterizing one particular interaction that the particle in question participates.

2. A more abstract possibility is that a given space-time sheet or boundary component can correspond to several p-adic primes. Indeed, a power series in powers of given integer n gives rise to a well-defined power series with respect to all prime factors of n and effective multi-p-adicity could emerge at the level of field equations in this manner.

One could say that space-time sheet or boundary component corresponds to several p-adic primes through its effective p-adic topology in a hologram like manner. This option is the most flexible one as far as physical interpretation is considered. It is also supported by the number theoretical considerations predicting the value of gravitational coupling constant [K23].

An attractive hypothesis is that only space-time sheets characterized by integers n_i having common prime factors can be connected by join along boundaries bonds and can interact by particle exchanges and that each prime p in the decomposition corresponds to a particular interaction mediated by an elementary boson characterized by this prime.

The physics of quarks and hadrons provides an immediate test for this interpretation. The surprising and poorly understood conclusion from the p-adic mass calculations was that the p-adic primes characterizing light quarks u, d, s satisfy $k_q < 107$, where $k = 107$ characterizes hadronic space-time sheet [K16].

1. The interpretation of $k = 107$ space-time sheet as a hadronic space-time sheet implies that quarks topologically condense at this space-time sheet so that $k = 107$ cannot belong to the collection of primes characterizing quark.

2. Quark space-time sheets must satisfy $k_q < 107$ unless $\hbar$ is large for the hadronic space-time sheet so that one has $k_{eff} = 107+22 = 129$. This predicts two kinds of hadrons. Low energy hadrons consists of u, d, and s quarks with $k_q < 107$ so that hadronic space-time sheet must correspond to $k_{eff} = 129$ and large value of $\hbar$. One can speak of confined phase. This allows also $k = 127$ light variants of quarks appearing in the model of atomic nucleus [K22]. The hadrons consisting of c, t, b and the p-adically scaled up variants of u, d, s having $k_q > 107$, $\hbar$ has its ordinary value in accordance with the idea about asymptotic freedom and the view that the states in question correspond to short-lived resonances.

4 The New Space Time Picture And Some Of Its Consequences

The previous considerations suggest that TGD space-time has a hierarchical, fractal like structure consisting of an infinite number of condensate levels n characterized by length scale $L(n) < L(n+1)$ identifiable as a typical size for 3-surface at level n. Spin glass analogy suggests that the label n corresponds to preferred primes characterizing p-adic length scales and to values of Planck constant labelling levels of dark matter hierarchy. p-Adic fractality means that for each p there is actually a length scale hierarchy coming in powers of $\sqrt{p}$. An infinite hierarchy of copies of standard model physics is an unavoidable prediction if quantum classical correspondence is taken seriously and can be identified as dark matter hierarchy.

4.1 Topological Condensation And Formation Of Bound States

It is tempting to identify the physical counterpart of the topological condensate in the length scale L as a bound state with size L. If this assumption is accepted then one ends up to the rather beautiful general scenario for the hierarchical structure of the 3-space. Quarks (3-surface of size of CP_2 length, so called CP_2 type extremals to be discussed later) condense around the hadronic 3-surfaces, hadrons condense around a piece of Minkowski space with size of order $10^{-14} - 10^{-15}$ meters to form nuclei, nuclei and electrons condense to form atoms of size of the order 10^{-10} meters or larger, atoms condense to form molecules, etc.

Generalizing the previous ideas, one ends up to a rather exciting possibility for a topological description of the macroscopic states of matter. Consider solids as an example. Solids correspond to a regular lattice of atomic or molecular 3-surfaces condensed to background 3-space. There are two kinds of forces binding the structure together.

i) There are interactions mediated via the the fields of the background 3-space and these correspond to the ordinary electric forces.

ii) There is interaction resulting from the "contacts" between the boundaries of the neighboring atoms (for a two-dimensional visualization see **Fig. 2**). flux tube means mathematically a tube $D^2 \times D^1$ connecting the boundaries together or equivalently, topological condensation for the boundaries. This interaction is completely new and has as its counterpart the forces generated by the electron exchange between atoms believed to explain the binding between the atoms of certain solids. It is however clear that something quite new is introduced so that the conventional belief that Schrödinger equation in a flat 3-space alone explains these interactions would not be correct in TGD context. That the approach based on Schrödinger equation have not lead to contradictions can be understood also: what flux tube makes is to select among possible solutions of Schrödinger equation those realized in Nature by forcing the Schrödinger amplitude to the bridges connecting different structural units.

/Users/mattipitkanen/dropbox/figures/solid.png

Figure 2: How one could understand the solid state topologically in terms of the join along boundaries interaction (or its flux tube counterpart): 2-dim. visualization

The topological description of the liquid state goes along similar lines. Now however the contacts between neighboring atoms are not so rigid the reason being that thermal noise continually splits these contacts. A completely new element is the emergence of the vacuum quantum numbers and should lead to effects differentiating between TGD and more conventional approaches.

4.2 3-Topology And Chemistry

The practical models for chemical systems rely on the assumption that a chemical element has a well defined geometric shape. If this assumption is made then Schrödinger equation in electronic degrees of freedom combined with symmetry considerations gives satisfactory results. The general belief is that the complete Scrödinger equation treating quantum mechanically also the positions of the atoms predicts also the geometric structure of the chemical compounds. Unfortunately, in practice it is not possible to check numerically the correctness of this belief.

The "join along boundaries" interaction (or its flux tube counterpart(is a second standard phenomenological concept in the chemistry. What happens that reactants join along a part of their boundaries together to form a transition state (or a final state) and the reaction takes place in the new geometry. The chemistry of the biological systems relies heavily on this concept. For example, the catalytic action of the enzymes is often understood on the basis of key and lock principle: enzyme acts on the protein only provided the surfaces of the protein and enzyme fit together like lock and key. Usually it is believed that the association of a geometric form to chemical compounds and the "join along boundaries" mechanism provide an easy short hand description, which is in principle derivable from the complete Schrödinger equations. TGD suggests that this is not be the case.

What is exciting that this kind of idea leads to a completely fresh approach to the understanding of bio-systems: the basic principles of the underlying the biochemistry could be formulated in terms of the 3-topology. The biological information processing could involve the manipulation of the 3-topology or more precisely: the manipulation of the boundary topology if "join along boundaries" (connection by flux tube) is indeed the basic mechanism. It should noticed also that the emergence of the vacuum quantum numbers is characteristic feature of TGD and provides a possible means for realizing the Universe as Computer idea in biological systems. xc

Decades after writing these lines it has become clear that Kähler action need not allow boundaries in the usual sense. They would be replaced with boundaries between space-time regions with Minkowskian and Euclidian signature and magnetic flux tubes carrying possibly monopole flux would replace join along boundaries bonds (JABs). Whether JAB or flux tube is involved does not matter in most considerations to follow and I will use these notions interchangeably.

4.3 3-Topology And Super-Conductivity

The #-contacts (wormholes) feeding the gauge fluxes from a given sheet of the 3-space to a larger one, can be regarded as particles carrying classical charges defined by the gauge fluxes. These particles must be light, which suggests that #-contacts can form Bose-Einstein condensate or coherent state identifiable in terms of Higgs vacuum expectation value. This BE condensate provides a possible explanation of so called Comorosan effect [I1] observed in organic molecules. A related effect is the formation of exotic atoms, when some valence electrons drop from the atomic space-time sheet to a larger space-time sheet. This process is accompanied by the generation of # contacts. The process leads to the effective lowering of the valence of the original atom and thus to "electronic alchemy". The claimed peculiar properties of so called ORMES [H1] could have explanation as exotic atoms as suggested in [K6, K7].

I have also suggested that the basic mechanism of super-conductivity somehow involves quantum coherent states of wormhole contacts. This might be the case although not quite in the original sense. There are two poorly understood problems involved with super-conductivity.

1. Super-conductor is often modelled as a coherent state of Cooper pairs. The conceptual problem is that the electric charge of this state is not well-defined and this is definitely in conflict with the conservation of electromagnetic charge.

2. The massivation of photons is a second poorly understood basic aspect of super-conductivity. The obvious question is whether this process could be interpreted in terms of a vacuum expectation value of a charged Higgs field and whether the charge of the Higgs field resolve the paradox otherwise created by the non-conservation of electromagnetic charge.

The obvious guess is that superconductor corresponds to superposition of quantum states with a well-defined total em charge such that electronic electromagnetically charge of some electronic

Cooper pairs has been transferred to neutral wormhole contacts having quantum numbers of charged left/right handed positron and neutral right/left handed neutrino so that some Cooper pairs themselves have been transmuted to neutrino Cooper pairs.

In ordinary phase a space-time sheet carrying N Cooper pairs would feed em charge to a larger space-time sheet by $2N$ wormhole contacts consisting of e^+e^- parton pair. Super-conducting phase would correspond to a superposition of states for which $2M \leq 2N$ wormhole contacts have become electromagnetically charged and $2M$ electrons have transformed to neutrinos. Coherent state would thus correspond to a superposition of states with $M \leq N$ neutrino pairs, $N - M$ Cooper pairs, and $2M$ charged wormhole contacts.

The presence of exotic W bosons mediating weak interactions in the scale of the space-time sheet would make possible this kind of states (which involved entanglement between wormhole contacts and Cooper pairs). The model would require that neutrinos and electrons in the superconducting phase have nearly identical masses and thus correspond to $p = M_{127}$, the largest Mersenne prime which corresponds to non-super-astronomical p-adic length scale. This conforms also with the absence of electro-weak symmetry breaking below the p-adic length scale characterizing the size of the Cooper pair. Also the quantum model for hearing [K19] requires that exotic neutrinos with mass very near to electron mass are involved. The TGD based model for atomic nucleus [K22] in turn predicts that quarks with mass near to electron mass appear at the ends of the color bonds connecting nucleons.

4.4 Macroscopic Bodies As A Topology Of 3-Space

The natural generalization of the foregoing ideas is that even the macroscopic bodies of the everyday world correspond to 3-surfaces, which have suffered topological condensation to the background 3-space. The outer surfaces of the macroscopic bodies would correspond to the boundaries of a particular space-time sheet. When macroscopic bodies touch each other, a partial join along boundaries (or formation of flux tube connection) would take place. We would live in the middle of a wild science fiction without realizing it!

Paradoxically, this new interaction is extremely familiar for us. The surface of the Earth corresponds to a boundary of a rather big 3-surface. At smaller length scales we see flowers, trees and all kinds of things and also these are 3-surfaces, which have joined along their boundaries to the surface of the Earth. Our biological bodies correspond to 3-surfaces having boundaries. We have however the special ability to cut this contact rather easily and to move quite freely although the gravitational force acting in the background 3- space takes care that the join along the boundaries with the surface of Earth is the usual state of affairs. When I touch the surface of the table by finger, a join along boundaries interaction (or its flux tube counterpart) takes place: we even recognize different objects just by touching them. We also smell and taste and at the microscopic level these senses are based on the join along boundaries interaction. Despite all this it has not been explicitly recognized that the formation of the flux tube might be a fundamental physical interaction!

What is also amusing that the implicit assumptions of any physical model of the macroscopic world is based on the assumptions about the geometric form of the physical objects and also the join along boundaries interaction is introduced implicitly into the description. For example, in order to describe solid state one draws lattice: one draws atoms in this lattice and bonds between the atoms. A second example is provided by the description of mechanical system consisting of rigid bodies.

In present picture this description is obtained by projecting the boundary of the 3- space to flat space E^3: matter in the conventional sense corresponds to the shadow of the boundary-topology of 3-surface (for a 2-dimensional illustration see **Fig.3**). The fact that this kind of description is so obvious masks the fact that it is far from trivial whether one can actually deduce this kind of description starting from wave mechanics or QED.

What is so exciting that we can deduce the rough features of the topology of the surrounding 3-space just by looking it in various scales! Single glance shows that this topology is extremely complicated and contains boundaries everywhere and in all scales. In any case, it is in principle possible to make a map of a 3-surface in H both by observation of the form of macroscopic bodies and by measuring the ordinary physical observables like electromagnetic fields. Note that

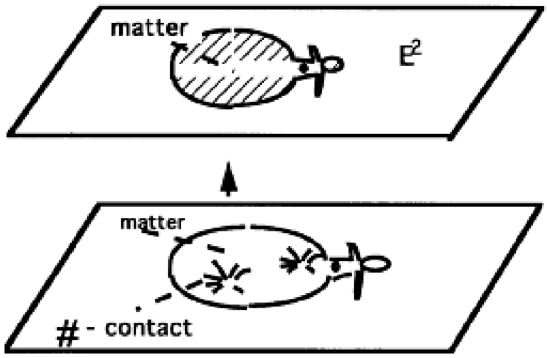

Figure 3: 3-dimensional matter as projection of the boundary of 3-surface to E^3: 2-dim. visualization

the fractal properties of the world are in accordance with the prediction of RGI hypothesis that topological condensate has hierarchical structure containing 3-surfaces of all possible sizes.

To summarize, topological condensation seems to provide a purely topological description for the generation of structures. The concept of matter in topologically trivial, almost flat 3-space is replaced with an empty but topologically highly nontrivial 3-space. The idea leads to a concrete program of actually finding out what is the topology of a given form of matter and understanding the physical properties matter in terms of this topology! And it would surprising if this kind of understanding would not increase our abilities to control and manipulate the properties of the matter.

4.4.1 Topological field quantum as a coherent quantum system

There are several arguments suggesting that topological field quanta are good candidates for coherent quantum systems and that join along boundaries provides basic means for constructing larger quantum systems from smaller units.

1. The choice of the coordinates inside a given field quantum is analogous to the choice of the quantization axis. This suggests that the topological field quanta might provide a topological description of certain aspects of quantum phenomena. The choice of the quantization axis could indeed correspond to that taking place in quantum measurement. The fact that the quantization axes associated with different connected 3-surfaces need not be the same is in accordance with the idea that quantum coherence is possible for a connected 3-surface only. An exception is provided by a system consisting of several topological field quanta connected by "bridges" (flux tubes), for which quantization axis are same and which therefore can be be regarded as a coherent quantum system. As an example consider a spinning particle in a constant magnetic field. To describe the situation one must construct the imbedding of the magnetic field on the particle 3-surface by requiring that the resulting 4-surfaces corresponds to a preferred extremals of Kähler action. The simplest manner to achieve this is to assume that the quantization axis defining the vacuum quantum numbers n_1 and n_2 is in the direction of the magnetic field so that one say that the external magnetic field fixes the quantization axis.

2. 3-surfaces consisting of several field quanta are in general unstable in accordance with that fact that the formation of macroscopic quantum systems is also a rare phenomenon. The argument goes as follows.
   i) CP_2 coordinates tend to have discontinuous or have even infinite derivatives at the boundaries of the topological field quanta if one poses some rather sensible physical requirements

like the requirement that the 3-surface provides an imbedding for the Kähler electric field created by the mass distribution. As a consequence, Einstein tensor contains delta function type singularities and this is not nice. The best manner to avoid the edges is to allow boundaries.
ii) The boundaries of a 3-surface consisting of several field quanta are in general carriers of surface Kähler (Z^0) charge as the following argument shows. The embedding of the Kähler electric field associated with a given matter distribution has certain critical radius, which corresponds to the boundary of a field quantum. In general, one cannot continue the imbedding to a neighboring field quantum without allowing infinite derivatives of CP_2 coordinates.
iii) The 3-surface consisting of several field quanta is not stable unless the condition $u = cos(\Theta) = \pm 1$ is satisfied on $r = \infty$ surfaces. The point is that the excitations of Φ coordinate in general imply discontinuity of 3-surface at the boundary unless they are strongly correlated for neighboring field quanta.

3. The gluing of topological field quanta is probably possible by the flux tubes. The tube $D^2 \times D^1$ or the "bridge" between the two topological field quanta corresponds to a topological field quantum. The most probable "hot spots", where the gluing is possible correspond to parts of the surface, where the normal component of the Kähler electric field is vanishing. Now however the stability of the flux tube is not obvious. It can also happen that the directions of the induced Kähler fields are same on some portions of the boundaries and in this case the gluing by joing along boundaries bond serving as a Kähler electric flux tube is possible: in this case the stability of the bond is obvious. The color electric flux tubes between valence quarks provide a good example of this.

4.4.2 Topological description of supra phases

The topological construction recipe of a supra phase could be following. Take volumes of ordinary phase with a size of order of coherence length ξ, topologically condense them to the background 3-space and construct "bridges" between the boundaries of these structures. Supra phase is destroyed if the bridges are cut either thermally or by external magnetic field: the introduction of an external magnetic field indeed destroys the bridge since it implies that the quantum numbers n_1 and n_2 become in general non-vanishing inside the field quanta and bridge so that the order parameter ψ becomes discontinuous on the boundaries of bridges.

In the ground state of the supra phase the order parameter describing the supra phase is covariantly constant. Since the topology of the join along boundaries condensate is extremely complicated, the first homotopy group of the condensate is nontrivial. This means that one in general cannot find a global gauge transformation gauging the gauge potential associated with a vanishing magnetic field away. This implies that the phase increment of the order parameter along a closed homotopically nontrivial loop is in general nontrivial. These increments obviously contain information coded into the order parameter about the topology of the join along boundaries/flux tube condensate.

The BE condensate of the charged # contacts, giving rise to pseudo super conductivity, playd a key role in the earlier TGD inspired model of brain as a macroscopic quantum system. In the model discussed in this chapter the coherent state of Cooper pairs is replaced with an entangled state involving product states of $2M$ charged wormhole contacts, $N - M$ electronic Cooper pairs, and M neutrino cooper pairs. One can also ask whether the vacuum quantum numbers might provide a realization for the idea about Universe as Computer. Biological information processing might be based on the manipulation of the vacuum quantum numbers. These ideas will be developed in some detail in the last part of the book.

4.4.3 Topological description of dissipation

The previous topological ideas lead to a general ideas about how structures are generated at macroscopic level. There is however a standard approach to the description of the generation of structures [B2] and in this approach dissipative mechanisms play central role. The basic idea is that dissipation takes care that an open system ends up to some asymptotic state, which need not be thermal equilibrium but can be a complicated dynamic, non-equilibrium state.

The topological definition of the quantum coherence suggests that these approaches are in fact very closely related. Dissipation means certainly a loss of quantum coherence since for a coherent quantum system density matrix develops unitarily so that dissipation is impossible. Quantum coherence is lost at a given level of condensation hierarchy if the condensate consists of several 3-surfaces interacting through standard interactions only. The formation of the flux tubes however creates quantum coherence. Therefore the breaking of the flux tubes provides a good candidate for a fundamental dissipation mechanism.

To make the idea more concrete consider as an example liquid flow, assuming that there is a velocity gradient in a direction orthogonal to the velocity. What one wants to understand is the friction or how the energy of the liquid is dissipated. Liquid molecules have typically flux tubes (tube $D^2 \times D^1$) with the neighboring molecules (and due to thermal motion these contacts are continuously splitting and rejoining. The average age of a typical contact is much smaller than the time scale associated with the motion of a liquid so that the contact between two neighboring molecules suffers several thermally induced splittings and re-joinings, when the neighboring molecule pass by. A natural assumption is that the contact between two neighboring molecules is like a rubber band: energy is needed to stretch it. Assume that contact is formed between neighboring atoms moving with certain relative velocity so that the contact gets longer and splits after certain average time. The energy needed to stretch the contact longer is taken from the energy of the translational motion so that the relative motion becomes slightly slower.

As a second example, consider the understanding of the finite conductivity in metals. The neighboring atoms in the metal form a lattice and there are contacts between the neighboring atoms. These contacts are not completely stable but suffer splittings now and then. The large conductivity of the metal results from these contacts since they provide for the conduction electrons the bridges to move from one atomic 3-surface to a another one. The finiteness of the conductivity results from the fact that now and then a bridge between two neighboring atoms is broken. In the last part of the book it will be found that this kind of argument leads to a correct order of magnitude estimate for the metallic conductivity using a TGD inspired modification of the Drude model.

The concept of topological condensate affords also a second new point of view concerning the description of dissipation. The standard description of dissipation is in terms of inelastic collisions of particles. This description generalizes: particles at the condensate level n correspond to topological field quanta of level $n-1$ with typical size $L(n-1)$. In inelastic collisions of these particles join along boundaries contacts are created and split and part of kinetic energy is transferred to the kinetic energy of topological field quanta of level $n-2$ condensed on level $n-1$ field quanta. This mechanism makes possible the gradual transfer of the kinetic energy to the atomic length scales, where the collisions of ordinary particles take care of the further dissipation. Some potential applications of this picture are provided by hydrodynamics: ordinary hydrodynamics generalizes to a hierarchy of hydrodynamics, one for each condensate level plus a model for the energy and momentum transfer between two subsequent levels.

5 Topological Condensation And Color Confinement

In this section a simple semiclassical model of color confinement is constructed as an application of the previous ideas. Also a view about color confinement being based on the same mechanism as the generation of macroscopic and macro-temporal quantum coherence (crucial for the TGD inspired theory of consciousness [K13] is discussed. These two arguments are separated by a temporal distance longer than decade and their different style reflects the development of my own thinking about TGD.

5.1 Explanation Of Color Confinement Using Quantum Classical Correspondence

One can understand color confinement from the properties of the Kähler action by applying quantum classical correspondence.

1. The classical color gauge field is proportional to $H^A J_{\alpha\beta}$, where H^A is color Hamiltonian. This implies that the color holonomy group is Abelian. This suggests strongly that the

physical states correspond states of color multiplets having vanishing color hyper charge and isospin. This would mean a weak form of color confinement.

2. The proportionality of the gluon field to the induced Kähler field, approximately satisfying free Maxwell equations, implies that the direction of the classical color field in M^4 is not random and that gluon field behaves in this sense as a massless field giving rise to long range interactions. The approximate canonical invariance of the Maxwell phase, which corresponds to the exact canonical gauge invariance of WCW geometry, is realized as approximately local $U(1)$ transformations which become constant color rotations below a cutoff scale identifiable as the size of space-time sheet carrying color charge.

3. The fact that the classical color field is proportional to a color Hamiltonian and Kähler field implies that the direction of the gluon field in the color algebra is random above the cutoff length scale so that color cannot propagate in length scales longer than the cutoff scale. Since color gauge currents are conserved for CP_2 type extremals representing wormhole contacts, color gauge flux is conserved in wormhole contacts which are therefore color neutral as particles so that colored variant of Higgs mechanism is not possible. The finite range of color interaction therefore leaves only the possibility that the net color charge of the elementary particles topologically condensed at the hadronic space-time sheet vanishes.

5.2 Hadrons As Color Magnetic/Electric Flux Tubes

In this model quarks and gluons correspond to small M^4 type surfaces containing topologically condensed CP_2 type extremals and these surfaces are in turn condensed on a larger hadronic M^4 type surface. Valence quarks (at least) are connected by color electric or magnetic flux tubes (flux tubes) to form color singlets.

At elementary particle level, topological condensation means the condensation of the CP_2 type extremals around M^4 type surfaces. The condensed CP_2 type extremals perform zitterbewegung with a velocity of light although cm is at rest. The 3-space surrounding the condensed elementary particle has a finite size of the order of Compton radius (natural guess at this stage). At length scales $r << r_c$ (r_c denotes the Compton radius of the particle), condensed particles look essentially like massless particles whereas at length scales $r >> r_C$ they look like pieces of M^4 condensed to the background and moving with a velocity smaller than light velocity. CP_2 type extremals can be regarded as Kähler magnetic monopoles, whose magnetic flux runs in the internal degrees of freedom so that no long range $1/r^2$ magnetic field is generated. The fact that elementary particles are in a well defined sense Kähler magnetic monopoles supports criticality hypothesis: the strong Kähler coupling phase for the electric charges must be identical with the weak coupling phase for the magnetic monopoles and therefore Kähler action must correspond to a fixed point of the coupling constant evolution (this does not exclude the p-adic coupling constant evolution with respect to the zero modes of the Kähler metric).

The construction of WCW geometry and of quantum TGD lead to the conclusion that the description of the non-perturbative aspects of the color interaction must be based on the flux variables defined by the induced Kähler form. These variables include as a special case the generalized classical color fluxes. Since the low energy limit of TGD is expected to be more or less equivalent with the standard model, one can ask whether color confinement is signalled also by the divergence of the color coupling strength at low energies. p-Adic length scale hypothesis makes it possible to quantitative understand the confinement scale.

There are good reasons to expect that the quantum average space-time associated with a hadron could be regarded as an orbit of a 3-surface obtained by connecting the 3-surfaces (of size smaller than hadronic size) associated with the valence quarks with color electric flux tubes to get a color singlet state. Color singletness results from the randomness of the direction of the color field above hadronic length scales implying that the average radial color gauge flux emanating from the hadron vanish. This structure in turn has suffered a topological condensation on a larger hadronic 3-surface. The cutting of one or more color electric flux tube leads automatically to a generation of compensating color charges so that only color singlets can be created in the decays of the hadron. Also the topological evaporation of only color singlet objects is possible.

5.2.1 Color magnetic or electric flux tubes or both?

Both color magnetic and electric flux tubes have been used to model hadrons in TGD framework as well as in QCD, and one might wonder which of these options is the correct one. This depends on what the precise identification of preferred extremals is, and here not final view has emerged. For absolute minimization of Kähler action - the original identification for preferred extremal property (probably not correct) - Kähler electric fields are favored so that color electric flux tubes would be in a preferred position as models of hadron. For the more general variational principle discussed in [K25] the absolute value of Kähler action for space-time region with a definite sign of action density is either minimized or maximized (these options define dual dynamics and are consistent with the fact that 3-surfaces rather than 4-surfaces are fundamental dynamical objects). Therefore both Kähler magnetic and electric flux tubes are possible so that both color electric and magnetic models can be said to be correct.

The notion of absolute minimization does not make sense in p-adic context unless one manages to reduce it to purely algebraic conditions. Therefore it is better to talk just about preferred extremals of Kähler action and accept as the fact that there are several proposals for what this notion could mean. For instance, one can consider the identification of space-time surface as quaternionic sub-manifold meaning that tangent space of space-time surface can be regarded as quaternionic sub-manifold of complexified octonions defining tangent space of imbedding space. One manner to define "quaternionic sub-manifold" is by introducing octonionic representation of imbedding space gamma matrices identified as tangent space vectors. It must be also assumed that the tangent space contains a preferred complex (commutative) sub-space at each point and defining an integrable distribution having identification as string world sheet (also slicing of space-time sheet by string world sheets can be considered). Associativity and commutativity would define the basic dynamical principle. A closely related approach is based on so called Hamilton-Jacobi structure [K4] defining also this kind of slicing and the approaches could be equivalent. A further approach is based on the identification of preferred extremal property as quantum criticality [K4]. What the exact formulation for preferred extremal property is, does not have relevance in the following considerations.

The simplest model for the color flux tube connecting two quarks is based on the following picture.

1. The CP_2 type extremals with quark quantum numbers are topologically condensed at M^4 type 3-surfaces with size smaller than the hadronic size. These 2-surfaces are in turn condensed on the hadronic 3-surface. Quark like 3-surfaces are connected by join along boundaries contacts, which are color flux tubes connecting the boundaries of the quark 3-surfaces. These color flux tubes are the counterparts of the hadronic string.

2. The color magnetic/electric flux tube is a deformation of a vacuum extremal of type $M^2 \times D^2$ ("spring"), where D^2 is a disk orthogonal to M^2. This surface indeed looks like a tube of cross section D^2. The disk has an area of order $1/T$, where T is hadronic string tension.

3. The quarks at the ends of the flux tube serve as sources of approximately constant Kähler magnetic/electric fields (giving rise to chromo-electric fields of confining type), which generate the hadronic string tension. Since color field is proportional to Kähler field, also the Kähler charge of quark and gluon is of order $q \simeq 1$. The proportionality of the induced Kähler field and classical color field implies that hadrons can be regarded as chromo-electric flux tubes. Also QCD [B1, B3] affords this kind of descriptions for color confinement.

5.2.2 A model for color electric flux tube

Consider now in a more detail the model for the Kähler electric flux tube understood as a preferred extremal of the Kähler action. Since the actual situation is rather complicated it is useful to consider a simplified situation that is solution of the field equations with essentially constant Kähler electric field in the axal direction inside a cylinder of M^4.

The flux tube (color electric flux tube) corresponds to a surface of representable as a map from $M^4 = M^2 \times D^2$ to the homologically nontrivial geodesic sphere of type II. Here D^2 is a disk corresponding to the transversal section of the color flux tube and has size not much smaller than a typical hadronic length. One expects the Kähler action to be lowered by the generation of the Kähler electric fields. Field equations for the small deformations reduce in the lowest order to free Maxwell equations

$$D_\beta J^{\alpha\beta} = 0 \ . \tag{5.1}$$

Topologically condensed valence quarks at the ends of the flux tube serve as sources for the Kähler electric field.

The solution ansatz describing a constant Kähler electric field is obtained as a map from $M^4 = M^2 \times D^2$ to the geodesic sphere of type II:

$$\begin{aligned} cos(\Theta) &= u(z) \ , \\ \Phi &= \omega t \ . \end{aligned} \tag{5.2}$$

The interesting components of the induced metric and induced Kähler form are given by the expressions

$$\begin{aligned} g_{tt} &= 1 - \frac{R^2\omega^2}{4}(1-u^2) \ , \\ g_{zz} &= -1 - \frac{R^2}{4}\frac{u_{,z}^2}{(1-u^2)} \ , \\ J_{tz} &= \frac{u_{,z}\omega}{4} \ . \end{aligned} \tag{5.3}$$

Field equations are obtained from the conservation of four-momentum and the conservation condition for the z-component of momentum gives

$$u_{,z}^2(g_{zz}^3 g_{tt})^{-1/2} = \frac{E}{\omega^2} \ , \tag{5.4}$$

where E can be interpreted as the constant field strength.

The lowest order solution is obtained by approximating the induced metric with a flat metric so that one has

$$\Theta = arccos(\frac{Ez}{\omega}) \ . \tag{5.5}$$

The solution obtained is well defined only for the values of z having absolute value smaller that $2\pi/E$ and the g_{zz} component of the induced metric becomes infinite at the critical values of z. One might think that the appearance of the singularity is an artefact of the approximation used but this is not the case. The closer examination of the field equations shows that the singularity is unavoidable and results from the compactness of CP_2 (vector potential is proportional to $u = cos(\Theta)$) and that one cannot continue the solution in any manner for larger values of z. The nice thing is that boundary conditions are satisfied due to the singularity of the metric in the direction of the Kähler electric field. The result implies that the length of the string, and therefore the size of the hadron, is of order

$$L \sim \frac{2\pi\omega}{E} \ .$$

The hadronic string tension is generated dynamically. One can obtain an estimate for the string tension by noticing that the situation is to a good approximation one-dimensional. This means that the Kähler electric field of the point charge is constant. Since the Kähler charges of quarks serve as sources of the Kähler field the order of magnitude for the Kähler electric field is given from Gauss theorem

$$E = \frac{q}{S} \ . \tag{5.6}$$

where $q \simeq 1$ is the Kähler charge of quark and S is the transverse area of the string. The order of magnitude estimate $q \simeq 1$ follows from the requirement that the color charges for quarks have this order of magnitude and from the fact that classical gluon field is proportional to the Kähler field. Hadronic string tension is obtained by integrating the energy momentum density over the transversal degrees of freedom

$$T \simeq \frac{1}{8\pi\alpha_K}\int E^2 dS \simeq \frac{1}{8\pi\alpha_K}\frac{q^2}{S} \ . \tag{5.7}$$

This implies that the transversal size of the hadronic string is of the order of $S \simeq 1/GeV^2$. For ground state hadrons the length of the string is therefore of same order as the transversal size of the string. Despite this, hadrons are string like objects in a well defined sense: their topology is $D^1 \times S^2$ instead of $D^1 \times D^2$.

As already found, the imbedding of the constant Kähler electric electric field associated with the flux tube becomes singular for values $z = \pm 2\pi\omega/E$ of the coordinate variable z in the direction of E (ω is the frequency associated with the solution). The study of the spherically symmetric extremal revealed that the parameter ω has value of order $10^{-4}m_{Pl}$ in long length scales. For the hadronic space-time sheet ω must of the order $\omega \sim 1/L$, where L is a typical hadronic length in order to get reasonable length for the string like object.

5.3 Color Confinement And Generation Of Macro-Temporal Quantum Coherence

How macroscopic quantum coherence is possible in macroscopic time scales? This pressing problem of quantum consciousness theories involves both the question what coherence and de-coherence really mean and what really happens in quantum jump, as well as the question how the de-coherence times in living matter could be much longer than predicted by standard physics. Color confinement is the pressing problem of particle physics apparently put under the rug during last two decades. There might be a close connection between these seemingly totally un-related puzzles as the following little argument tends to show.

5.3.1 Classical argument: the time spent in color bound states is very long

The TGD based solution to the problem how to achieve macro-temporal quantum coherence relies on the new physics predicted by quantum TGD. The decisive factor is the gigantic almost degeneracy of states due to the fact that CP_2 canonical transformations, which effectively act as $U(1)$ gauge transformations, are approximate symmetries of the Kähler action broken only by the classical gravitation.

The argument goes as follows.

1. The increment of the psychological time in single quantum jump is estimated to be about CP_2 time, that is about 10^4 Planck times. During this time interval quantum coherence is destroyed in zero mode degrees freedom representing macroscopic degrees of freedom as well as in all degrees of freedom in which there is no bound state entanglement. This time interval is extremely brief as compared to the actual de-coherence times, which standard quantum theory allows to estimate.

2. The formation of bound states can save the situation since bound state entanglement is not reduced during state preparation phase of the quantum jump consisting of self measurements. The transformation of the zero modes (macroscopic classical degrees of freedom in which localization occurs in each quantum jump) to quantum fluctuating degrees of freedom, when flux tubes are formed between two space-time sheets representing binding systems accompanies the formation of bound states. The reason is that only over all center of mass zero modes remain zero modes. This means that the generation of macroscopic quantum fluctuating degrees of freedom and the formation of bound states accompany each other.

3. When bound state entanglement is generated, state function reduction and state preparation cease to occur in these degrees of freedom and one has macro-temporal quantum coherence.

The sequence of quantum jumps effectively binds to a single quantum jump just like elementary particles bind to form atom behaving effectively as single elementary particle. The lifetime of the bound state defines the de-coherence time.

4. This does not yet explain why the lifetimes of the bound states, or more precisely, why the time spent in bound states, is much longer than predicted by the standard physics. New physics is required for this, and spin glass degeneracy provides it. What happens is following. When a bound state is formed, the space-time sheets representing the free particles are connected by flux tubes. By quantum spin glass degeneracy the number of bound states is huge as compared to the number of free states, since there is extremely large number of flux tube configurations and differing only by the classical gravitational energy. Accordingly, the time spent in bound states, and thus also de-coherence time, is much longer than that predicted by standard physics.

How could one understand color confinement in this picture? The idea is simple: when quarks form color bound states, they are connected by color flux tubes (this is the aspect of confinement which goes outside QCD). Also color flux tubes possess huge spin glass degeneracy. Free quark states do not possess this degeneracy since join along boundaries bonds/flux tubes are absent. Thus the time spent in free states in which color flux tubes are absent is negligible to the time time spent in color bound states so that the states consisting of free quarks are unobservable. If this picture is correct, the divergence of the color coupling strength in confinement length scale reflects mathematically the fact that number of bound states is overwhelmingly large as compared that for the free states.

5.3.2 Color confinement from unitarity and spin glass degeneracy

A more precise phrasing of the idea about the connection between spin glass degeneracy and color confinement relies on unitarity conditions and the assumptions $T_{MN} \simeq T$ and $T_{Mr} \simeq T_r$. Here capital subscripts refer to degenerate hadronic states and small letter subscripts to free many-quark states. In this idealization hadronic degenerate states are stable against decay to free many-quark states with only single exception. The exceptional state should act as a doorway making possible the transition to quark-gluon plasma phase.

The S-matrix can be written as sum of unit matrix and reaction matrix T: $S = 1 + iT$.

1. The unitarity conditions $SS^\dagger = 1$ read in terms of T-matrix as

$$i(T - T^\dagger) = TT^\dagger \quad . \tag{5.8}$$

For diagonal elements one has

$$2 \times Im(T_{mm}) \quad = \quad \sum_r |T_{mr}|^2 \geq 0 \quad . \tag{5.9}$$

What is essential that the right hand side is non-negative and closely related to the total rate of transitions. If this rate is high also the imaginary part at the left hand side of the equation is large and therefore also the rate for the diagonal transition. For instance, in the case of low energy strong interactions this implies that the total reaction rates are high but transitions occur mostly in the forward direction. In this case the mere large number of final many-hadron states implies that most transitions occur in the forward direction.

In the recent case one must consider both free many quark states and their bound states. Let us use capitals M, N as labels for bound states and small letters m, n as labels for free states.

2. The diagonal unitarity conditions can be written for both of these states as

$$\begin{aligned} 2Im(T_{mm}) &= \sum_r |T_{mr}|^2 + \sum_R |T_{mR}|^2 \geq 0 \ , \\ 2Im(T_{MM}) &= \sum_R |T_{MR}|^2 + \sum_r |T_{Mr}|^2 \geq 0 \ . \end{aligned} \quad (5.10)$$

In both cases there is a large number of the degenerate states involved at the right hand side so that one expects that the right hand side has a large value. For bound states the number of degenerate states is much higher due to the additional degeneracy brought in by the flux tubes (color flux tubes). Thus the lifetime and de-coherence time should be considerably longer than expected on basis of standard physics.

3. For the non-diagonal transitions from bound states to free states one has

$$i(T_{Mm} - \overline{T}_{mM}) = \sum_r T_{Mr}\overline{T}_{mr} + \sum_R T_{MR}\overline{T}_{mR} \ . \quad (5.11)$$

The right hand side is not positive definite and since a large number of amplitudes between widely different free and bound states of quarks are involved, one expects that a destructive interference occurs. This is consistent with a small value of the non-diagonal amplitudes T_{Mm} and with the long lifetime of bound states.

4. What happens for non-diagonal transitions between degenerate states? The unitarity conditions read as

$$\begin{aligned} i(T_{mn} - \overline{T}_{nm}) &= \sum_r T_{mr}\overline{T}_{nr} + \sum_r T_{mR}\overline{T}_{nR} \ , \\ i(T_{MN} - \overline{T}_{NM}) &= \sum_R T_{MR}\overline{T}_{NR} + \sum_r T_{Mr}\overline{T}_{Nr} \ . \end{aligned} \quad (5.12)$$

The right hand side is not anymore positive definite and there is a very large number of summands present. Hence a destructive interference could occur and the amplitude would be very strongly restricted in the forward direction. This need not however be true in the case of degenerate states since they are expected to be very similar to each other.

5. One can indeed play with the idealization that the transition amplitudes between degenerate states are identical $T_{MN} = T$ and that the amplitudes T_{Mr} are independent of M and given by $T_{Mr} = T_r$.

   In this case T-matrix would have the form $T = t \times X$, where X is a matrix for which all elements are equal to one. t can be written as $|t|exp(i\phi)$. T-matrix is maximally degenerate and the diagonalized form T^D of T-matrix has only a single non-vanishing element equal to Nt, N the number of degenerate states. t must satisfy the unitarity condition $|t| = 2 \times sin(\phi)/N$. S-matrix would reduce to an almost unit matrix for the diagonalized bound states.

   What about the stability of the bound states in this case? The decay amplitudes for bound states corresponding to the vanishing eigen values of T are given by $T^D(M,r) = \sum c_M T_{Mr} = \sum_M c_M \times T_r = 0$ by the orthogonality of these states with the state with a non-vanishing eigen value. Thus the lifetimes of all bound states expect the one with the non-vanishing eigen value of T are infinitely long in this idealization.

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