

Topological Geometrodynamics: What Might Be the First Principles?

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http://tgd.wippiespace.com/public_html/.

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Abstract

A brief summary of various competing visions about the basic principles of quantum Topological Geometrodynamics (TGD) and about tensions between them is given with emphasis on the recent developments. These visions are following. Quantum physics as classical spinor field geometry of the "world of classical worlds" consisting of light-like 3-surfaces of the 8-D imbedding space $H = M^4 \times CP_2$; zero energy ontology in which physical states correspond to physical events; TGD as almost topological quantum field theory for light-like 3-surfaces; physics as a generalized number theory with associativity defining the fundamental dynamical principle and involving a generalization of the number concept based on the fusion of real and p-adic number fields to a larger book like structure, the identification of real and various p-adic physics as algebraic completions of rational physics, and the notion of infinite prime; the identification of configuration space Clifford algebra elements as hyper-octonionic conformal fields with associativity condition implying what might be called number theoretic compactification; a generalization of quantum theory based on the introduction of hierarchy of Planck constants realized geometrically via a generalization of the notion of imbedding space H to a book like structure with pages which are coverings and orbifolds of H ; the notion of finite measurement resolution realized in terms of inclusions of hyperfinite factors as the fundamental dynamical principle implying a generalization of S-matrix to M-matrix identified as Connes tensor product for positive and negative energy parts of zero energy states; two different kinds of extended super-conformal symmetries assignable to the light-cone of H and to the light-like 3-surfaces leading to a concrete construction recipe of M-matrix in terms of generalized Feynman diagrams having light-like 3-surfaces as lines and allowing to formulate generalized Einstein's equations in terms of coset construction.

Keywords: Topological Geometrodynamics, unified theories, symmetries, dynamical principles.

1 Introduction

While pondering how to make the writing of an overall view about basic principles and applications of quantum TGD [16, 17, 63, 64, 65] a more interesting task than mere updating of what I have written earlier, I realized that the tension between two profoundly different approaches to physics might bring in a new perspective making the writing process and perhaps even its outcome more interesting. Einstein characterizes the difference of these two approaches in the following manner.

We can distinguish various kind of theories in physics. Most of them are constructive. They attempt to build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme from which they start out. Thus the kinetic theory of gases seeks to reduce mechanical, thermal, and diffusional processes to movements of molecules - i.e., to build them up out of the hypothesis of molecular motion. When we say that we have succeeded in understanding a group of natural processes, we invariably mean that a constructive theory has been found which covers the processes in question.

Along with this most important class of theories there exists a second, which I will call "principle-theories." These employ the analytic, not the synthetic, method. The elements which form their basis and starting-point are not hypothetically constructed but empirically discovered ones, general characteristics of natural processes, principles that give rise to mathematically formulated criteria which the separate processes or the theoretical representations of them have to satisfy. Thus the science of thermodynamics seeks by analytical means to deduce necessary conditions, which separate events have to satisfy, from the universally experienced fact that perpetual motion is impossible.

The advantages of the constructive theory are completeness, adaptability, and clearness, those of the principle theory are logical perfection and security of the foundations. The theory of relativity belongs to the latter class.

Theoretician probably agrees with Einstein that the identification of first principles is the basic goal. Unfortunately, the first principle approach sooner or

later leads to astray if some principle happens to be wrong. Einstein himself was not able to accept the non-deterministic aspect of quantum physics and used rest of his life to fruitless attempts to get rid of it. I believe that the almost non-existence of theoretical biology and neuroscience is due to the adherence to the materialistic and reductionistic dogmas and to the stubborn belief that biology cannot teach anything to physicist at the level of fundamental principles. I also believe that the degeneration of superstring theory - once thought to be the ultimate victory of the reductionistic approach - to landscape misery is due to the refusal to realize that something is badly wrong at the level of first principles.

Therefore it seems that one most tolerate the tension created by the simultaneous application of both the analytic approach deducing predictions from believed-to-be first principles and the synthetic approach which I understand as a continual challenging of these principles. I have felt very intensively the tension between these approaches during the three decades that I have spent in attempts to identify the fundamental principles that would allow to build around the basic idea of TGD a computational machinery allowing to make precise quantitative predictions. What looked for some years to be nothing but a technical challenge of developing a perturbative approach based on path integral formalism has led to a profound restructuring of the basic ontology. Mention only the new view about time, the notion of many-sheeted space-time, p-adic physics, zero energy ontology, a generalization of quantum physics itself based on the hierarchy of Planck constants involving also a generalization of the notion of 8-D imbedding space $M^4 \times CP_2$, and extension of quantum physics to a quantum theory of consciousness.

This process is by no means over yet. I do not have explicit formulas for S-matrix elements and even during last two years several new ideas have emerged at fundamental level. A more precise basic formulation of quantum TGD in terms of M-matrix generalizing the notion of S-matrix in the framework of zero energy ontology relying on the notion of finite resolution of quantum measurement represents perhaps the most important step of progress [22]. The improved understanding of the relationship between

experienced time and geometric time [49] has led to a more detailed picture about p-adic coupling constant evolution and p-adic length scale hypothesis can be now deduced from the first principles [22, 24]. The surprise was that p-adic length scale hypothesis assigns with every elementary particle a fundamental macroscopic time scale characterizing the temporal span of the zero energy space-time sheet associated with the particle. This time scale has nothing to do with the lifetime of the particle. In the case of electron the time scale .1 seconds which happens to be a fundamental biorhythm. An improved understanding of Higgs mechanism and quantum classical correspondence has also emerged [24].

In this article I will discuss and compare different first principle approaches to quantum TGD.

1. Physics as the classical spinor field geometry of the world of classical worlds (WCW) is the oldest and best developed approach to TGD and means generalization of Einstein's program of geometrizing classical physics so that it applies to entire quantum physics.
2. Parton level formulation of quantum TGD as an almost topological quantum field theory using light-like 3-surfaces as fundamental objects allows a detailed understanding of superconformal symmetries generalizing those of super string models. A category theoretical interpretation of M-matrix as a functor is possible. This picture has tight connections to the physics as configuration space geometry approach and implies it.
3. Physics as generalized number theory represents third vision about TGD. Number theoretic universality meaning a fusion of real and p-adic physics to single coherent whole forces a formulation in terms of so called number theoretic braids. The symmetries of classical number fields strongly suggest the interpretation in terms of standard model symmetries and a number theoretic interpretation of the imbedding space $M^4 \times CP_2$. Associativity condition would define laws of classical and quantum TGD. The notion of infinite prime defines a third thread
4. The identification of configuration space Clifford algebra as hyper-octonion valued conformal fields having values in HFF gives allows to deduce most of the speculative "must-be-true's" of quantum TGD.
5. The idea about hierarchy of Planck constants was inspired by certain empirical facts. The hierarchy leads to a generalization of the notion of imbedding space emerges naturally from the requirement that the choice of quantization axes has a geometric correlate also at the level of imbedding space. The physical implication is the identification of dark matter in terms of a hierarchy of macroscopically quantum coherent phases with quantized values of Planck constant having arbitrarily large values and playing a key role, not only in biology but also in astrophysics and cosmology of TGD Universe. The hierarchy of Planck constants can be seen as necessary for the realization of quantum criticality. The generalization of imbedding space is also essential for the construction of the Kähler function of configuration space.
6. A further vision about quantum TGD is that the mere finiteness of measurement resolution fixes the scattering matrix of quantum TGD. In zero energy ontology S-matrix must be generalized to M-matrix identified as time-like entan-

gument coefficients between positive and negative energy parts of zero energy states. M-matrix can be regarded as a "complex square root" of density matrix expressible as product of a real square root of density matrix and unitary S-matrix: thermodynamics becomes part of quantum theory. Hyper-finite factors of type II_1 (HFFs) emerge naturally through Clifford algebra of WCW and allow a formulation of quantum measurement theory with a finite measurement resolution. The notion of finite measurement resolution expressed in terms of inclusion of HFFs with included algebra defining the measurement resolution leads to an identification of M-matrix in terms of Connes tensor product and a simple argument shows that M-matrix is unique apart from the presence of the square root of density matrix needed by thermodynamics. Coupling constant evolution corresponds to a hierarchy of measurement resolutions and p-adic coupling constant hypothesis follows as a consequence with an additional prediction assigning to particles an additional time scale characterizing temporal distance between positive and negative energy parts of corresponding zero energy state: for electron this time scale is .1 second, fundamental biorhythm. Thus zero energy ontology implies a direct connection between elementary particle physics and biology.

7. Super-conformal symmetries define basic element of quantum TGD, and one might argue that these symmetries alone dictate to high degree the physics. Quite recently it turned that also symplectic variant of conformal field theory emerges very naturally in TGD framework (super-canonical symmetries) and this led to a concrete proposal for how to construct n-point functions needed to calculate M-matrix.
8. Consciousness theory interpreted as generalization of quantum measurement theory the most plausible vision about quantum TGD and has already shown its power and brought into theory notions which cannot be imagined in the standard conceptual framework of quantum physics.

2 What might be the first principles of quantum TGD

In the following I want to summarize different visions about first principles of quantum TGD emphasizing the tension between analytic and synthetic approaches. The first principle approaches are following:

1. Generalization of Einstein's program of geometrizing classical physics so that quantum theory can be seen as a theory of *classical* spinor fields in WCW consisting of light-like 3-surfaces and possessing Kähler geometry [18, 19, 20];
2. Quantum TGD as almost topological field theory with fundamental objects identified as light-like 3-surfaces and possessing generalization of super-conformal symmetries of string models as symmetries [21, 22];
3. Physics as a generalized number theory involving three different threads corresponding to need fuse real and various p-adic physics to single coherent whole [33], the possibility that standard model symmetries and dynamics of quantum and classical TGD could be dictated in terms of classical number fields [34], and the ideas inspired by the notion of infinite prime [35];
4. The identification of configuration space gamma matrices as hyper-octonion valued conformal fields having values in HFF gives hopes of deducing space-time and imbedding space as emergent concepts;
5. The hierarchy of large Planck constants as a manner to realize quantum criticality [26];
6. Zero energy ontology and the vision that finite measurement resolution formulated in terms of inclusions of certain von Neumann algebras known as hyperfinite factors of type II_1 allows to fix quantum dynamics completely and interpret quantum theory as square root of thermodynamics [22];

7. Super-conformal symmetries define basic element of quantum TGD, and one might argue that these symmetries alone dictate to high degree the physics. Quite recently it turned that also symplectic variant of conformal field theory emerges very naturally in TGD framework (super-canonical symmetries) and this led to a concrete proposal for how to construct n-point functions needed to calculate M-matrix;
8. Quantum theory of consciousness as a generalization of quantum measurement theory to include observer to the theory [46].

There is of course also the tension between these different visions. How these approaches relate to each other and can one build bridges between them?

2.1 From Equivalence Principle to zero energy ontology

The tension between analytic and constructive approaches is present even in Einstein's own theory and was the basic stimulus leading to TGD. Equivalence Principle states that gravitational and inertial masses are identical. This statement is however rather problematic as Einstein himself was first to admit. Einstein's equations express the identity for gravitational and inertial energy momentum densities as a consequence of a variational principle. There is however no global version of this statement because one cannot define the notions of inertial and gravitational four-momenta without adherence to perturbative approach.

The hypothesis that space-times are 4-D surfaces of a higher-dimensional space-time of form $H = M^4 \times S$ resolves the problem: since Poincare symmetries become symmetries of H rather than space-time itself. Inertial four-momentum can be defined as a conserved Noether charge and also gravitational four-momentum can be regarded as a Noether charge albeit non-conserved. Equivalence Principle can hold true only under some additional conditions. For instance, for the imbeddings of Robertson-Walker cosmologies inertial four-momentum density vanishes unlike gravitational four-momentum density, which

for a long time remained quite a mystery. The real understanding of the situation became possible only after the introduction of what I call zero energy ontology [22].

In zero energy ontology one replaces positive energy states with zero energy states with positive and negative energy parts of the state at the boundaries of future and past direct light-cones forming a causal diamond. All conserved quantum numbers of the positive and negative energy states are of opposite sign so that these states can be created from vacuum. "Any physical state is creatable from vacuum" becomes thus a basic principle of quantum TGD and together with the notion of quantum jump resolves several philosophical problems (What was the initial state of universe?, What are the values of conserved quantities for Universe, Is theory building completely useless if only single solution of field equations is realized?).

At the level of elementary particle physics positive and negative energy parts of zero energy state are interpreted as initial and final states of a particle reaction so that quantum states become physical events. Equivalence Principle would hold true in the sense that the classical gravitational four-momentum of the vacuum extremal whose small deformations appear as the argument of configuration space spinor field is equal to the positive energy of the positive energy part of the zero energy quantum state. Equivalence Principle is expected to hold true for elementary particles and their composites but not for the quantum states defined around non-vacuum extremals.

More precisely, the inertial four-momentum assignable to the 3-D Chern-Simons action is non-vanishing only if one adds to the CP_2 Kähler form a pure gauge part $A_a = constant$, where a denotes light cone proper time [20]. A breaking of Poincare invariance is implied which is however compensated by the fact that configuration space corresponds to the union of configuration spaces associated with future and past directed light-cones. If the vacuum extremal is also an extremal of the curvature scalar, gravitational four-momentum is conserved.

In the case of CP_2 type vacuum extremal gravitational stationarity transforms the M^4 projection of the extremal from a random light-like curve to a light-

like geodesic allowing an interpretation as incoming or outgoing on mass shell particle. General vacuum extremal corresponds to a virtual particle. At the classical level Equivalence Principle requires that the light-like gravitational four-momentum of CP_2 vacuum extremal co-incides with the light-like inertial four-momentum associated with Chern-Simons action in this situation. This condition relates the value of A_a to gravitational constant G and CP_2 radius R . G would thus appear as a fundamental constant and quantum criticality should dictate the ratio G/R^2 .

The strong form of Equivalence Principle would require that the classical 4-momentum associated with Kähler action of allowed small deformations co-incides with the conserved gravitational four-momentum of the vacuum extremal extremizing curvature scalar: this might have a natural interpretation in terms of Bohr orbitology but is not be consistent with zero energy ontology inspired picture unless one has double sheeted structure with sheets possessing opposite energies such that double sheeted structure is approximated by single sheet with Robertson-Walker cosmology in GRT framework. The identification of gauge bosons as wormhole contacts and gravitons as pairs of wormhole supports double sheeted structure with sheets possessing opposite arrows of geometric time.

A rather promising first principle formulation of Equivalence Principle relies on generalized conformal invariance. The general view about particle massivation is based on the generalized coset construction allowing to understand the p-adic thermal contribution to mass squared as a thermal expectation value of the conformal weight for super Kac-Moody Virasoro algebra ($SKMV$) or equivalently super-canonical Virasoro algebra (SCV) [21]. Conformal invariance holds true only for the differences of $SKMV$ and SCV generators which annihilate physical states. In the case of SCV and $SKMV$ only the generators G_n, L_n , $n > 0$, annihilate the physical states. The actions of SCV generators and $SKMV$ generators on physical states are identical by coset construction. The interpretation is in terms of Equivalence Principle since $SKMV$ corresponds rather naturally to gravitational four-momentum and SCV to inertial four-momentum (this applies also to inertial and grav-

itational color quantum numbers). The conditions stating the vanishing of the differences of the generators become the TGD counterpart for Einstein's equations. The mathematical justification for this picture comes from the possibility to lift the SC algebra from $\delta M_{\pm}^4 \times CP_2$ and SKM algebra from the partonic 3-surface X^3 to the level of imbedding space to hyper-complex and perhaps even hyper-quaternionic algebra. Here the basic prerequisite for number theoretic compactification to be discussed later plays a key role.

2.2 Physics as a physics of classical spinor fields in the world of classical worlds?

The oldest vision relies on the identification of quantum physics as a unique completely classical physics of spinor fields in WCW (configuration space) with quantum jump being the only genuinely quantal element in this approach. This means a generalization of Einstein's geometrization program to the level of quantum theory. Fermi statistics finds geometrization: the anti-commutation relations for the configuration space gamma matrices correspond to the anticommutation relations for fermionic oscillator operators associated with free induced spinor fields of imbedding space space-time sheets. Gamma matrices define also fermionic generators of a super-conformal algebra.

The needed infinite-dimensional Kähler geometry exists only if it has maximal group of isometries, and a generalization of super conformal symmetries of super string models emerges naturally in this approach and dictates the dynamics to a high degree [18, 19, 20]. One might even hope that physics is completely unique from the mere requirement that this geometry exists mathematically. General coordinate invariance requires that the definition of Kähler geometry in terms of Kähler function assigns to 3-surface a highly unique space-time surface: the interpretation is as the analog of Bohr orbit so that classical theory becomes exact part of quantum theory. Kähler function is identified as a preferred extremal for so called Kähler action which is essentially

Maxwell action for the induced Kähler form of CP_2 .

Quantum criticality is the basic dynamical principle in this approach and implies that the only coupling constant of the theory - Kähler coupling strength - is analogous to a critical temperature and follows as a prediction.

2.3 Is the dynamics of quantum TGD fixed from lightlikeness of 3-surfaces?

The 4-D general coordinate invariance leads naturally to the identification of lightlike 3-D surfaces as fundamental dynamical objects. These light-like 3-surfaces correspond to light-like orbits of throats of CP_2 sized wormhole contacts connecting so called CP_2 type extremal to a space-time sheet or CP_2 extremals connecting two space-time sheets to each other. In the case of fermions there is only single wormhole throat carrying fermion number. In the case of bosons connecting two space-time sheets throats carry opposite fermion numbers. Locally one can interpret light-like 3-surfaces as random orbits of partonic 2-surfaces moving with local light-velocity.

The first implication of the light-likeness is metric two-dimensionality meaning a generalization [21] of the super-conformal symmetries of super-string models [79, 80]. Conformal invariance in turn means that the basic objects are in a well-defined sense 1-D strings. This does not however mean that TGD would degenerate to a theory of 2-D or 1-D fundamental objects (this fear generated one of the long lasting tensions!). The generalized conformal invariance is not global: light-like 3-surfaces decompose into 3-D regions inside which generalized conformal invariance holds true so that 3-dimensionality remains in a discrete sense. Global 2-D conformal invariance for partonic 2-surface fails in a similar manner which means discretized 2-dimensionality. Local 1-dimensionality in turn reduces to discreteness at the fundamental level by the finiteness of quantum measurement resolution. Discrete 4-dimensionality is implied in an analogous manner.

This vision leads to a profound understanding of quantum TGD as almost topological quantum field

theory (TQFT [74]) based on the analog of Chern-Simons action and its fermionic counterpart [20, 22]. The attribute "almost" is forced by the light-likeness condition involving induced metric and means that metric related quantum numbers such as energy and momentum characterize physical states. This theory should have conformal field theories as basic building blocks. Also a connection with category theoretical ideas emerges.

Concerning the tension with geometric approach can be resolved by deducing from 3-D description the 4-D description based on Kähler function from the parton level description. Quantum classical correspondence should justify the basic assumption of the quantum measurement theory that quantum transitions have classical space-time correlates (for instance, measurement of spin component leads to spitting of electron beam in Stern-Gerlach experiment). In other words, the 4-D description based on geometrized classical fields should provide 4-D space-time correlate for the fundamental quantum description in terms of 3-D light-like surfaces. This correspondence is in some sense dual of the holographic principle in M-theory.

Consistency requirement allows to guess concrete formulas for the exponent of Kähler function in terms of Dirac determinants associated with the modified Dirac operator defined at light-like partonic 3-surfaces [20]. Also explicit recipes for how to construct the 4-D space-time sheets as preferred extremals of Kähler action emerge. Discretization is present in terms of what I call number theoretical braids. The tension however remains: these formulas are educated guesses inspired by the general principles.

2.4 Physics as a generalized number theory?

Physics as a generalized number theory vision involves actually three threads: p-adic ideas [33], the ideas related to classical number fields [34], and ideas related to the notion of infinite prime [35].

2.4.1 Fusion of real and p-adic physics to a coherent whole as guiding principle

p-Adic number fields were not present in the original approach to TGD. The success of the p-adic mass calculations [38, 39, 40, 41] made however clear that one must generalize the notion of topology also at the infinitesimal level from that defined by real numbers so that the attribute "topological" in TGD gains much more profound meaning than intended originally. It took a decade to get convinced that the identification of p-adic physics as a correlate of cognition and intentionality is probably correct [50] and that p-adic topology of p-adic space-time sheets induces the effective p-adic topology of real space-time sheets.

The original view about physics as the geometry of the world of the classical worlds is not enough to meet the challenge of unifying real and p-adic physics to a single coherent whole. This inspired "physics as a generalized number theory" approach [33, 34, 35] relying on a generalization of the notion of number obtained by "gluing" reals and various p-adic number fields and their algebraic extensions along common rationals and algebraics. The same gluing procedure for of real p-adic physics to a larger structure forces to introduce a discretization at space-time level in terms of rational and algebraic numbers.

The interpretation is in terms of cognitive, sensory, and measurement resolutions rather than fundamental discreteness of the space-time. What looks rather counter intuitive first is that transcendental points of p-adic space-time sheets are at spatiotemporal infinity in real sense so that the correlates of cognition and intentionality cannot be localized to any finite spatiotemporal volume unlike those of sensory experience. This description of intentionality and cognition in this manner predicts p-adic fractality of real physics meaning chaos in short scales combined with long range correlations: p-adic mass calculations represent one example of p-adic fractality.

There is also a tension between p-adication program and physics as infinite-D configuration space geometry and TGD as almost TQFT approaches. They seem to be consistent. The discretization forced by p-adicization leads to the notion of number theoretic braid - braids are indeed fundamental objects of 3-D

TQFTs- and also to a guess for the formula for the exponent of Kähler function in terms of data associated with number theoretic braids associated with a given collection of light-like 3-surfaces.

2.4.2 Classical number fields and associativity and commutativity as fundamental law of physics

The dimensions of classical number fields appear as dimensions of basic objects in quantum TGD. Imbedding space has dimension 8, space-time has dimension 4, light-like 3-surfaces are orbits of 2-D partonic surfaces, and by conformal invariance one-dimensional structures are basic objects. The lowest level corresponds to discrete sets of points identifiable as intersections of real and p-adic space-time sheets. This suggests that besides p-adic number fields also classical number fields (reals, complex numbers, quaternions, octonions [81]) are involved [34] and the notion of geometry generalizes considerably. In the recent view about quantum TGD the dimensional hierarchy defined by classical number field indeed plays a key role. $H = M^4 \times CP_2$ as number theoretic interpretation and standard model symmetries can be understood number theoretically as symmetries of hyper-quaternionic planes of hyper-octonionic space.

The associativity condition $A(BC) = (AB)C$ suggests itself as a fundamental physical law of both classical and quantum physics. Commutativity can be considered as an additional condition. In conformal field theories associativity condition indeed fixes the n-point functions of the theory. At the level of classical TGD this means that space-time surfaces can be identified as maximal associative (hyper-quaternionic) sub-manifolds $X^4 \subset M^8$. As a matter fact, commutativity in number theoretic sense is a further natural condition and it will be found that this leads to the notion of number theoretic braid naturally as also to direct connection with super string models.

This leads to the notion of number theoretic compactification analogous to the dualities of M-theory.

1. The first question is how to map the light-like 3-surfaces $X_l^3 \subset M^8$ to the corresponding 3-

surfaces $X_l^3 \subset H$. Second question is how the 4-surfaces $X^4(X_l^3)$ in M^8 and H relate.

2. The basic observation is that if the tangent spaces of the points of the hyper-quaternionic surface $X^4(X^3) \subset M^8$ contain a preferred hyper-complex plane M^2 in its tangent space $T(X^4)$, $X^4 \subset M^8$ can be mapped to $X^4 \subset H$. It is not clear whether the image represents a preferred extremal of Kähler action. It also seems that $M^2 \subset T(X^4)$ is not satisfied globally for all known extremals of Kähler action (say cosmic strings of form $X^2 \times Y^2 \subset M^4 \times CP_2$ unless they are straight).
3. This suggests that the correspondence at the level of 4-surfaces might be too strong a condition. The weaker condition requires that only light-like 3-surfaces $X_l^3 \subset M^8$ can be mapped to $X_l^3 \subset H$. This is true if for any connected component $X_{l,i}^3$ of X_l^3 one has $M^2 \subset T(X^4(X_{l,i}^3))$ at all points of $X_{l,i}^3$. M^2 , which has interpretation as the plane of non-physical polarizations, can depend on the connected component. This condition fixes the tangent space of $X^4(X^3)$ at X^3 and thus assigns to X_l^3 a preferred hyper-quaternionic surface in M^8 and a preferred extremal of Kähler action in H . This is enough for the purposes of quantum TGD. The only conjecture would be that the possible action assignable to the hyper-quaternionic 4-surface equals to the Kähler action.

M^4 and the hierarchy finite fields-rationals-reals-complex numbers-quaternions-octonions could have direct quantum physical counterpart [34]. Note that quaternions and octonions make sense for rationals and their algebraic extensions which make sense both in real and p-adic sense but p-adic sense quaternions and octonions fail to be number fields. The finiteness of measurement resolution restricts the consideration also to algebraic extensions of rationals.

The tension with the vision about physics as infinite-D configuration space geometry might be resolvable. It would not be surprising if the uniqueness of infinite-dimensional Kähler geometric existence would require that the isometries and holonomies of

imbedding space defining standard model symmetries correspond to a group having a number theoretic interpretation and that $X^4 \subset M^4 \times CP_2$ would be preferred by its number theoretic interpretation [34].

2.4.3 Infinite primes and quantum physics

The hierarchy of infinite primes (and of integers and rationals) [35] was the first mathematical notion stimulated by TGD inspired theory of consciousness. The construction recipe is equivalent with a repeated second quantization of super-symmetric arithmetic quantum field theory with bosons and fermions labeled by primes such that the many particle states of previous level become the elementary particles of new level. The hierarchy of space-time sheets with many particle states of space-time sheet becoming elementary particles at the next level of hierarchy and also the hierarchy of n:th order logics are also possible correlates for this hierarchy. For instance, the description of proton as an elementary fermion would be in a well defined sense exact in TGD Universe.

This construction leads also to a number theoretic generalization of space-time point since given real number has infinitely rich number theoretical structure not visible at the level of the real norm of the number a due to the existence of real units expressible in terms of ratios of infinite integers. This number theoretical anatomy suggest kind of number theoretical Brahman=Atman principle stating that the set consisting of number theoretic variants of single point of the imbedding space (equivalent in real sense) is able to represent the points of WCW or maybe even quantum states of the Universe [66]. Also a formulation in terms of number theoretic holography is possible.

Just for fun and to test these ideas one can consider a model for the representation of the configuration space spinor fields in terms of algebraic holography. I have considered guesses for this kind of map earlier [36, 35] and it is interesting to find whether additional constraints coming from zero energy ontology and finite measurement resolution might give. The identification of quantum corrections as insertion of zero energy states in time scale below measurement resolution to positive or negative energy part of zero

energy state and the identification of number theoretic braid as a space-time correlate for the finite measurement resolution give considerable additional constraints.

1. The fundamental representation space consists of wave functions in the Cartesian power U^8 of space U of real units associated with any point of H . That there are 8 real units rather than one is somewhat disturbing: this point will be discussed below. Real units are ratios of infinite integers having interpretation as positive and negative energy states of a super-symmetric arithmetic QFT at some level of hierarchy of second quantizations. Real units have vanishing net quantum numbers so that only zero energy states defining the basis for configuration space spinor fields should be mapped to them. In the general case quantum superpositions of these basis states should be mapped to the quantum superpositions of real units. The first guess is that real units represent a basis for configuration space spinor fields constructed by applying bosonic and fermionic generators of super-canonical and super Kac-Moody type algebras to the vacuum state.
2. What can one say about this map bringing in mind Gödel numbering? Each pair of bosonic and corresponding fermionic generator at the lowest level must be mapped to its own finite prime. If this map is specified, the map is fixed at the higher levels of the hierarchy. There exists an infinite number of this kind of correspondences. To achieve some uniqueness, one should have some natural ordering which one might hope to reflect real physics. The irreps of the (non-simple) Lie group involved can be ordered almost uniquely. For simple group this ordering would be with respect to the sum $N = N_F + N_{F,c}$ of the numbers N_F resp. $N_{F,c}$ of the fundamental representation resp. its conjugate appearing in the minimal tensor product giving the irrep. The generalization to non-simple case should use the sum of the integers N_i for different factors for factor groups. Groups themselves could be

ordered by some criterion, say dimension. The states of a given representation could be mapped to subsequent finite primes in an order respecting some natural ordering of the states by the values of quantum numbers from negative to positive (say spin for $SU(2)$ and color isospin and hypercharge for $SU(3)$). This would require the ordering of the Cartesian factors of non-simple group, ordering of quantum numbers for each simple group, and ordering of values of each quantum number from positive to negative.

The presence of conformal weights brings in an additional complication. One cannot use conformal as a primary orderer since the number of $SO(3) \times SU(3)$ irreps in the super-canonical sector is infinite. The requirement that the probabilities predicted by p-adic thermodynamics are rational numbers or equivalently that there is a length scale cutoff, implies a cutoff in conformal weight. The vision about M-matrix forces to conclude that different values of the total conformal weight n for the quantum state correspond to summands in a direct sum of HFFs. If so, the introduction of the conformal weight would mean for a given summand only the assignment n conformal weights to a given Lie-algebra generator. For each representation of the Lie group one would have n copies ordered with respect to the value of n and mapped to primes in this order.

3. Cognitive representations associated with the points in a subset, call it P , of the discrete intersection of p-adic and real space-time sheets, defining number theoretic braids, would be in question. Large number of partonic surfaces can be involved and only few of them need to contribute to P in the measurement resolution used. The fixing of P means measurement of N positions of H and each point carries fermion or anti-fermion numbers. A more general situation corresponds to plane wave type state obtained as superposition of these states. The condition of rationality or at least algebraicity means that discrete variants of plane waves are in question.

4. By the finiteness of the measurement resolution configuration space spinor field decomposes into a product of two parts or in more general case, to their superposition. The part Ψ_+ , which is above measurement resolution, is representable using the information contained by P , coded by the product of second quantized induced spinor field at points of P , and provided by physical experiments. Configuration space "orbital" degrees of freedom should not contribute since these points are fixed in H .
5. The second part of the configuration space spinor field, call it Ψ_- , corresponds to the information below the measurement resolution and assignable with the complement of P and mappable to the structure of real units associated with the points of P . This part has vanishing net quantum numbers and is a superposition over the elements of the basis of CH spinor fields and mapped to a quantum superposition of real units. The representation of Ψ_- as a Schrödinger amplitude in the space of real units could be highly unique. Algebraic holography principle would state that the information below measurement resolution is mapped to a Schrödinger amplitude in space of real units associated with the points of P .
6. This would be also a representation for perceiver-external world duality. The correlation function in which P appears would code for the information appearing in M-matrix representing the laws of physics as seen by conscious entity about external world as an outsider. The quantum superposition of real units would represent the purely subjective information about the part of universe below measurement resolution.

There is an objection against this picture. One obtains an 8-plet of arithmetic zero energy states rather than one state only. What this strange 8-fold way could mean?

1. The crucial observation is that hyper-finite factor of type II_1 (HFF) creates states for which center of mass degrees of freedom of 3-surface in

H are fixed. One should somehow generalize the operators creating local HFF states to fields in H , and an octonionic generalization of conformal field suggests itself. I have indeed proposed a quantum octonionic generalization of HFF extending to an HFF valued field Ψ in 8-D quantum octonionic space with the property that maximal quantum commutative sub-space corresponds to hyper-octonions [25]. This construction raises $X^4 \subset M^8$ and by number theoretic compactification also $X^4 \subset H$ in a unique position since non-associativity of hyper-octonions does not allow to identify the algebra of HFF valued fields in M^8 with HFF itself.

2. The value of Ψ in the space of quantum octonions restricted to a maximal commutative subspace can be expressed in terms of 8 HFF valued coefficients of hyper-octonion units. By the hyper-octonionic generalization of conformal invariance all these 8 coefficients must represent zero energy HFF states. The restriction of Ψ to a given point of P would give a state, which has 8 HFF valued components and Brahman=Atman identity would map these components to U^8 associated with P . One might perhaps say that 8 zero energy states are needed in order to code the information about the H positions of points P . The condition that Ψ represents a state with vanishing quantum numbers gives additional constraints. The interpretation inspired by finite measurement resolution is that the coordinate h associated with Ψ corresponds to a zero energy insertion to a positive or negative energy state localizable to a causal diamond inside the upper or lower half of the causal diamond of observer. Below measurement resolution for imbedding space coordinates $\Psi(h)$ would correspond to a nonlocal operator creating a zero energy state. This would mean that Brahman=Atman would apply to the mini-worlds below the measurement resolution rather than to entire Universe but by algebraic fractality of HFFs this would not be a dramatic loss.

2.5 Configuration space gamma matrices as hyper-octonionic conformal fields having values in HFF?

The fantastic properties of HFFs of type II_1 inspire the idea that a localized hyper-octonionic version of Clifford algebra of configuration space might allow to see space-time, embedding space, and configuration space as emergent structures. Surprisingly, commutativity and associativity imply most of the speculative "must-be-true's" of quantum TGD.

Configuration space gamma matrices act only in vibrational degrees of freedom of 3-surface. One must also include center of mass degrees of freedom which appear as zero modes. The natural idea is that the resulting local gamma matrices define a local version of HFF of type II_1 as a generalization of conformal field of gamma matrices appearing super string models obtained by replacing complex numbers with hyper-octonions identified as a subspace of complexified octonions. As a matter fact, one can generalize octonions to quantum octonions for which quantum commutativity means restriction to a hyper-octonionic subspace of quantum octonions [25]. Non-associativity is essential for obtaining something non-trivial: otherwise this algebra reduces to HFF of type II_1 since matrix algebra as a tensor factor would give an algebra isomorphic with the original one. The octonionic variant of conformal invariance fixes the dependence of local gamma matrix field on the coordinate of HO . The coefficients of Laurent expansion of this field must commute with hyper-octonions.

WCW has been identified as a union of configuration spaces associated with M_{\pm}^4 labeled by points of H or equivalently HO . The choice of quantization axes certainly fixes a point of H (HO) as a point remaining fixed under $SO(1,3) \times U(2)$ ($SO(1,3) \times SO(4)$). The condition that hyper-quaternionic inverses of $M^4 \subset HO$ points exist suggest a restriction of arguments of the n-point function to the interior of M_{\pm}^4 in consistency with the fact that causal diamonds consisting of intersections of future and past directed light-cones are basic building bricks of the geometry of WCW.

Associativity condition for the n-point functions forces to restrict the arguments to a hyper-

quaternionic plane $HQ = M^4$ of HO . One can also consider the commutativity condition by requiring that arguments belong to a preferred commutative sub-space HC of HO . Fixing preferred real and imaginary units means a choice of $M^2 = HC$ interpreted as a partial choice of quantization axes. This has quite strong implications.

1. The hyper-quaternionic planes with a fixed choice of M^2 are labeled by points of CP_2 . If the condition $M^2 \subset T(X^4(X_l^3))$ is satisfied for each connected component of $X^4 3_l$ with M^2 possibly depending on the component, it is possible to map the connected components of $X_l^3 \subset M^8$ to $X_l^3 \subset H$ so that $HO - H$ duality ("number theoretic compactification") emerges in weak form. Hyper-quaternionic surface $X^4(X_l^3) \subset H$ would correspond to a preferred extremal of Kähler action but only via the boundary conditions. The physical interpretation would be as a global fixing of the plane of non-physical polarizations in M^8 for each connected component of X_l^3 separately. Standard model symmetries emerge naturally. This new result suggests rather direct connection with super string models. In super string models one can choose the polarization plane freely and one expects also now that the generalized choice $M^2 \subset M^4 \subset M^8$ of polarization plane can be made freely without losing Poincare invariance with reasonable assumption about zero energy states.
2. One would like to fix local tangent planes T^4 of X^4 at 3-D light-like surfaces X_l^3 fixing the preferred extremal of Kähler action defining the Bohr orbit. An additional direction t should be added to the tangent plane T^3 of X_l^3 to give T^4 . This is achieved if t belongs to M^2 and perhaps corresponds to a light-like vector in M^2 .
3. Assume that partonic 2-surfaces X belong to $\delta M_{\pm}^4 \subset HO$ defining ends of the causal diamond. This is obviously an additional boundary condition. Hence the points of partonic 2-surfaces are associative and can appear as arguments of n-point functions. One thus finds an explanation for the special role of partonic 2-surfaces and a

reason why for the role of light-cone boundary. Note that only the ends of lightlike 3-surfaces need intersect $M_{\pm}^4 \subset HO$. A stronger condition is that the pre-images of light-like 3-surfaces in H belong to $M_{\pm}^4 \subset HO$.

4. Commutativity condition is satisfied if the arguments of the n-point function belong to an intersection $X^2 \cap M^2 \subset HQ$ and this gives a discrete set of points as intersection of light-like radial geodesic and X^2 perhaps identifiable in terms of points in the intersection of number theoretic braids with δH_{\pm} . One should show that this set of points consists of rational or at most algebraic points. Here the possibility to choose X^2 to some degree could be essential. As a matter fact, any radial light ray from the tip of light-cone allows commutativity and one can consider the possibility of integrating over n-point functions with arguments at light ray to obtain maximal information. For the pre-images of light-like 3-surfaces commutativity would allow one-dimensional curves having interpretation as braid strands.

To sum up, this picture implies HO-H duality with a choice of a preferred imaginary unit fixing the plane of non-physical polarizations globally, standard model symmetries, and number theoretic braids. The introduction of hyper-octonions could be however criticized: could octonions and quaternions be enough after all? Could HO-H duality be replaced with O-H duality and be interpreted as the analog of Wick rotation? This would mean that quaternionic 4-surfaces in E^8 containing global polarization plane E^2 in their tangent spaces would be mapped by essentially by the same map to their counterparts in $M^4 \times CP_2$, and the time coordinate in E^8 would be identified as the real coordinate. Also light-cones in E^8 would make sense as the inverse images of M_{\pm}^4 .

2.6 Hierarchy of Planck constants and quantum criticality

The hypothesis about a hierarchy of Planck constants was motivated by anomalies of biophysics [61, 60, 62]

and of astrophysics [31, 32] and led to a further generalization of the notion of imbedding space providing a connection with quantum groups and a fundamental description of anyons and quantum Hall effect [26]. One can say that imbedding space has book like structure obtained by gluing together almost copies of imbedding space along 4-dimensional sub-manifolds playing the role of the back of the book. These almost copies are in well-defined sense constructed from products of factor and covering spaces of M^4 and CP_2 . Different pages of book would in general have different values of Planck constant. In the vertices of Feynman diagrams only particles of given sector with same Planck constant would appear so that the particles at different pages would be dark relative to each other. They would however interact via classical gauge fields and also by exchange of particles since the particles can tunnel between different pages. It seems that this notion of darkness -much weaker than the standard one - is consistent with empirical facts.

This approach to quantum TGD has been developing vigorously during last years and led to a general vision about the basic mechanisms of quantum biology [57, 61, 60, 58] and has also provided deep insights to TGD inspired theory of consciousness. In particular, certain mysterious looking findings about ionic currents through cell membrane can be understood if considerable fraction of ions are dark in the proposed sense [62].

The idea about hierarchy of Planck constants forces to consider the possibility that the notions of space-time and the generalization of the imbedding space $M^4 \times CP_2$ might emerge from something more fundamental. A unique octonionic generalization of HFF might be the unique fundamental structure [25].

There are tensions present also now. Is this generalization a mere ad hoc addition or does quantum TGD require it? The hierarchy seems to be necessary in order to realize quantum criticality mathematically. Quantum criticality would mean criticality with respect to phase transitions changing the value of Planck constant interpreted as a tunneling between different pages of the big book. In the recent parton level formulation of quantum TGD the Kähler function of the configuration space emerges as a Dirac determinant and the construction also as

signs 4-D space-time surface to a given collection of light-like 3-surfaces. Also this construction relies in an essential manner on the book like structure of the imbedding space.

2.7 Does the finiteness of measurement resolution dictate the laws of physics?

The hypothesis that the mere finiteness of measurement resolution could determine the laws of quantum physics [22] completely belongs to the category of not at all obvious first principles. The basic observation is that the Clifford algebra spanned by the gamma matrices of WCW represents a von Neumann algebra [68] known as hyperfinite factor of type II₁ (HFF) [26, 25, 22]. HFF [69, 75] is an algebraic fractal having infinite hierarchy of included subalgebras isomorphic to the algebra itself [76]. The structure of HFF is closely related to several notions of modern theoretical physics such as integrable statistical physical systems [77], anyons [72, 73], quantum groups and conformal field theories [70, 71], and knots and topological quantum field theories [78, 74].

Zero energy ontology is second key element. In zero energy ontology these inclusions allow an interpretation in terms of a finite measurement resolution: in the standard positive energy ontology this interpretation is not possible. Inclusion hierarchy defines in a natural manner the notion of coupling constant evolution and p-adic length scale hypothesis follows as a prediction. In this framework the extremely heavy machinery of renormalized quantum field theory involving the elimination of infinities is replaced by a precisely defined mathematical framework. More concretely, the included algebra creates states which are equivalent in the measurement resolution used. Zero energy states are associated with causal diamond formed by a pair of future and past directed light-cones having positive and negative energy parts of state at their boundaries. Zero energy state can be modified in a time scale shorter than the time scale of the zero energy state itself.

One can imagine two kinds of measurement resolutions. The element of the included algebra can leave

the quantum numbers of the positive and negative energy parts of the state invariant, which means that the action of subalgebra leaves M-matrix invariant. The action of the included algebra can also modify the quantum numbers of the positive and negative energy parts of the state such that the zero energy property is respected. In this case the Hermitian operators subalgebra must commute with M-matrix.

The temporal distance between the tips of light-cones corresponds to the secondary p-adic time scale $T_{p,2} = \sqrt{p}T_p$ by a simple argument based on the observation that light-like randomness of light-like 3-surface is analogous to Brownian motion. This gives the relationship $T_p = L_p^2/Rc$, where R is CP_2 size. The action of the included algebra corresponds to an addition of zero energy parts to either positive or negative energy part of the state and is like addition of quantum fluctuation below the time scale of the measurement resolution. The natural hierarchy of time scales is obtained as $T_n = 2^{-n}T$ since these insertions must belong to either upper or lower half of the causal diamond. This implies that preferred p-adic primes are near powers of 2. For electron the time scale in question is .1 seconds defining the fundamental biorhythm of 10 Hz.

M-matrix representing a generalization of S-matrix and expressible as a product of a positive square root of the density matrix and unitary S-matrix would define the dynamics of quantum theory [22]. The notion of thermodynamical state would cease to be a theoretical fiction and in a well-defined sense quantum theory could be regarded as a square root of thermodynamics. M-matrix is identifiable in terms of Connes tensor product [75] and therefore exists and is almost unique. Connes tensor product implies that the Hermitian elements of the included algebra commute with M-matrix and hence act like infinitesimal symmetries. A connection with integrable quantum field theories is suggestive. The remaining challenge is the calculation of M-matrix and the needed machinery might already exist.

The tension is present also now. The connection with visions should come from the discretization in terms of number theoretic braids providing space-time correlate for the finite measurement resolution and making p-adicization in terms of number theo-

retic braids possible. Number theoretic braids give a connection with the construction of configuration space geometry in terms of Dirac determinant and with TGD as almost TQFT and with conformal field theory approach. The mathematics for the inclusions of hyper-finite factors of type II₁ is also closely related to that for conformal field theories including quantum groups relating closely to Connes tensor product and non-commutativity.

2.8 Are both symplectic and conformal field theories be needed?

Symplectic (or canonical as I have called them) symmetries of $\delta M_+^4 \times CP_2$ (light-cone boundary briefly) act as isometries of WCW. One can see these symmetries as analogs of Kac-Moody type symmetries with symplectic transformations of $S^2 \times CP_2$, where S^2 is $r_M = \text{constant}$ sphere of lightcone boundary, made local with respect to the light-like radial coordinate r_M taking the role of complex coordinate. Thus finite-dimensional Lie group G is replaced with infinite-dimensional group of symplectic transformations. This inspires the question whether a symplectic analog of conformal field theory at $\delta M_+^4 \times CP_2$ could be relevant for the construction of n-point functions in quantum TGD and what general properties these n-point functions would have. This section appears already in the previous chapter about symmetries of quantum TGD [21] but because the results of the section provide the first concrete construction recipe of M-matrix in zero energy ontology, it is included also in this chapter.

2.8.1 Symplectic QFT at sphere

Actually the notion of symplectic QFT emerged as I tried to understand the properties of cosmic microwave background which comes from the sphere of last scattering which corresponds roughly to the age of 5×10^5 years [32]. In this situation vacuum extremals of Kähler action around almost unique critical Robertson-Walker cosmology imbeddable in $M^4 \times S^2$, where there is homologically trivial geodesic sphere of CP_2 . Vacuum extremal property is satisfied for any space-time surface which is surface in

$M^4 \times Y^2$, Y^2 a Lagrangian sub-manifold of CP_2 with vanishing induced Kähler form. Symplectic transformations of CP_2 and general coordinate transformations of M^4 are dynamical symmetries of the vacuum extremals so that the idea of symplectic QFT emerges natural. Therefore I shall consider first symplectic QFT at the sphere S^2 of last scattering with temperature fluctuation $\Delta T/T$ proportional to the fluctuation of the metric component g_{aa} in Robertson-Walker coordinates.

1. In quantum TGD the symplectic transformation of the light-cone boundary would induce action in WCW (light-like 3-surfaces). In the recent situation it is convenient to regard perturbations of CP_2 coordinates as fields at the sphere of last scattering (call it S^2) so that symplectic transformations of CP_2 would act in the field space whereas those of S^2 would act in the coordinate space just like conformal transformations. The deformation of the metric would be a symplectic field in S^2 . The symplectic dimension would be induced by the tensor properties of R-W metric in R-W coordinates: every S^2 coordinate index would correspond to one unit of symplectic dimension. The symplectic invariance in CP_2 degrees of freedom is guaranteed if the integration measure over the vacuum deformations is symplectic invariant. This symmetry does not play any role in the sequel.
2. For a symplectic scalar field $n \geq 3$ -point functions with a vanishing anomalous dimension would be functions of the symplectic invariants defined by the areas of geodesic polygons defined by subsets of the arguments as points of S^2 . Since n-polygon can be constructed from 3-polygons these invariants can be expressed as sums of the areas of 3-polygons expressible in terms of symplectic form. n-point functions would be constant if arguments are along geodesic circle since the areas of all sub-polygons would vanish in this case. The decomposition of n-polygon to 3-polygons brings in mind the decomposition of the n-point function of conformal field theory to products of 2-point functions

by using the fusion algebra of conformal fields (very symbolically $\Phi_k \Phi_l = c_{kl}^m \Phi_m$). This intuition seems to be correct.

3. Fusion rules stating the associativity of the products of fields at different points should generalize. In the recent case it is natural to assume a non-local form of fusion rules given in the case of symplectic scalars by the equation

$$\langle \Phi_k(s_1) \Phi_l(s_2) \rangle = \int c_{kl}^m f(A(s_1, s_2, s_3)) \Phi_m(s) d\mu_s$$

Here the coefficients c_{kl}^m are constants and $A(s_1, s_2, s_3)$ is the area of the geodesic triangle of S^2 defined by the symplectic measure and integration is over S^2 with symplectically invariant measure $d\mu_s$ defined by symplectic form of S^2 . Fusion rules pose powerful conditions on n-point functions and one can hope that the coefficients are fixed completely.

4. The application of fusion rules gives at the last step an expectation value of 1-point function of the product of the fields involves unit operator term $\int c_{kl} f(A(s_1, s_2, s)) d\mu_s$ so that one has

$$\langle \Phi_k(s_1) \Phi_l(s_2) \rangle = \int c_{kl} f(A(s_1, s_2, s)) d\mu_s .$$

Hence 2-point function is average of a 3-point function over the third argument. The absence of non-trivial symplectic invariants for 1-point function means that $n = 1$ are constant, most naturally vanishing, unless some kind of spontaneous symmetry breaking occurs. Since the function $f(A(s_1, s_2, s_3))$ is arbitrary, 2-point correlation function can have both signs. 2-point correlation function is invariant under rotations and reflections.

2.8.2 Symplectic QFT with spontaneous breaking of rotational and reflection symmetries

CMB data suggest breaking of rotational and reflection symmetries of S^2 . A possible mechanism of spontaneous symmetry breaking is based on the observation that in TGD framework the hierarchy of Planck constants assigns to each sector of the generalized imbedding space a preferred quantization axes. The selection of the quantization axis is coded also to the geometry of "world of classical worlds", and to the quantum fluctuations of the metric in particular. Clearly, symplectic QFT with spontaneous symmetry breaking would provide the sought-for really deep reason for the quantization of Planck constant in the proposed manner.

1. The coding of angular momentum quantization axis to the generalized imbedding space geometry allows to select South and North poles as preferred points of S^2 . To the three arguments s_1, s_2, s_3 of the 3-point function one can assign two squares with the added point being either North or South pole. The difference

$$\Delta A(s_1, s_2, s_3) \equiv A(s_1, s_2, s_3, N) - A(s_1, s_2, s_3, S)$$

of the corresponding areas defines a simple symplectic invariant breaking the reflection symmetry with respect to the equatorial plane. Note that ΔA vanishes if arguments lie along a geodesic line or if any two arguments co-incide. Quite generally, symplectic QFT differs from conformal QFT in that correlation functions do not possess singularities.

2. The reduction to 2-point correlation function gives a consistency conditions on the 3-point functions

$$\langle (\Phi_k(s_1) \Phi_l(s_2)) \Phi_m(s_3) \rangle = c_{kl}^m \langle \Phi_m(s_3) \rangle$$

(4) =

$$c_{kl}^r c_{rm} \int f(\Delta A(s_1, s_2, s)) f(\Delta A(s, s_3, t)) d\mu_s d\mu_t$$

(5)

Associativity requires that this expression equals to $\langle \Phi_k(s_1)(\Phi_l(s_2)\Phi_m(s_3)) \rangle$ and this gives additional conditions. Associativity conditions apply to $f(\Delta A)$ and could fix it highly uniquely.

3. 2-point correlation function would be given by

$$\langle \Phi_k(s_1)\Phi_l(s_2) \rangle = c_{kl} \int f(\Delta A(s_1, s_2, s)) d\mu_s$$

4. There is a clear difference between $n > 3$ and $n = 3$ cases: for $n > 3$ also non-convex polygons are possible: this means that the interior angle associated with some vertices of the polygon is larger than π . $n = 4$ theory is certainly well-defined, but one can argue that so are also $n > 4$ theories and skeptic would argue that this leads to an inflation of theories. TGD however allows only finite number of preferred points and fusion rules could eliminate the hierarchy of theories.
5. To sum up, the general predictions are following. Quite generally, for $f(0) = 0$ n-point correlation functions vanish if any two arguments co-incide which conforms with the spectrum of temperature fluctuations. It also implies that symplectic QFT is free of the usual singularities. For symmetry breaking scenario 3-point functions and thus also 2-point functions vanish also if s_1 and s_2 are at equator. All these are testable predictions using ensemble of CMB spectra.

2.8.3 Generalization to quantum TGD

Since number theoretic braids are the basic objects of quantum TGD, one can hope that the n-point functions assignable to them could code the properties of ground states and that one could separate from n-point functions the parts which correspond to the symplectic degrees of freedom acting as symmetries of vacuum extremals and isometries of the 'world of classical worlds'.

1. This approach indeed seems to generalize also to quantum TGD proper and the n-point functions associated with partonic 2-surfaces can be

decomposed in such a manner that one obtains coefficients which are symplectic invariants associated with both S^2 and CP_2 Kähler form.

2. Fusion rules imply that the gauge fluxes of respective Kähler forms over geodesic triangles associated with the S^2 and CP_2 projections of the arguments of 3-point function serve basic building blocks of the correlation functions. The North and South poles of S^2 and three poles of CP_2 can be used to construct symmetry breaking n-point functions as symplectic invariants. Non-trivial 1-point functions vanish also now.
3. The important implication is that n-point functions vanish when some of the arguments co-incide. This might play a crucial role in taming of the singularities: the basic general prediction of TGD is that standard infinities of local field theories should be absent and this mechanism might realize this expectation.

Next some more technical but elementary first guesses about what might be involved.

1. It is natural to introduce the moduli space for n-tuples of points of the symplectic manifold as the space of symplectic equivalence classes of n-tuples. In the case of sphere S^2 convex n-polygon allows $n + 1$ 3-sub-polygons and the areas of these provide symplectically invariant coordinates for the moduli space of symplectic equivalence classes of n-polygons (2^n -D space of polygons is reduced to $n + 1$ -D space). For non-convex polygons the number of 3-sub-polygons is reduced so that they seem to correspond to lower-dimensional sub-space. In the case of CP_2 n-polygon allows besides the areas of 3-polygons also 4-volumes of 5-polygons as fundamental symplectic invariants. The number of independent 5-polygons for n-polygon can be obtained by using induction: once the numbers $N(k, n)$ of independent $k \leq n$ -simplices are known for n-simplex, the numbers of $k \leq n + 1$ -simplices for $n + 1$ -polygon are obtained by adding one vertex so that by little visual gymnastics the numbers $N(k, n + 1)$ are given by

$N(k, n+1) = N(k-1, n) + N(k, n)$. In the case of CP_2 the allowance of 3 analogs $\{N, S, T\}$ of North and South poles of S^2 means that besides the areas of polygons (s_1, s_2, s_3) , (s_1, s_2, s_3, X) , (s_1, s_2, s_3, X, Y) , and (s_1, s_2, s_3, N, S, T) also the 4-volumes of 5-polygons (s_1, s_2, s_3, X, Y) , and of 6-polygon (s_1, s_2, s_3, N, S, T) , $X, Y \in \{N, S, T\}$ can appear as additional arguments in the definition of 3-point function.

2. What one really means with symplectic tensor is not clear since the naive first guess for the n-point function of tensor fields is not manifestly general coordinate invariant. For instance, in the model of CMB, the components of the metric deformation involving S^2 indices would be symplectic tensors. Tensorial n-point functions could be reduced to those for scalars obtained as inner products of tensors with Killing vector fields of $SO(3)$ at S^2 . Again a preferred choice of quantization axis would be introduced and special points would correspond to the singularities of the Killing vector fields.

The decomposition of Hamiltonians of the "world of classical worlds" expressible in terms of Hamiltonians of $S^2 \times CP_2$ to irreps of $SO(3)$ and $SU(3)$ could define the notion of symplectic tensor as the analog of spherical harmonic at the level of configuration space. Spin and gluon color would have natural interpretation as symplectic spin and color. The infinitesimal action of various Hamiltonians on n-point functions defined by Hamiltonians and their super counterparts is well-defined and group theoretical arguments allow to deduce general form of n-point functions in terms of symplectic invariants.

3. The need to unify p-adic and real physics by requiring them to be completions of rational physics, and the notion of finite measurement resolution suggest that discretization of also fusion algebra is necessary. The set of points appearing as arguments of n-point functions could be finite in a given resolution so that the p-adically troublesome integrals in the formulas for the fusion rules would be replaced with

sums. Perhaps rational/algebraic variants of $S^2 \times CP_2 = SO(3)/SO(2) \times SU(3)/U(2)$ obtained by replacing these groups with their rational/algebraic variants are involved. Tetrahedra, octahedra, and dodecahedra suggest themselves as simplest candidates for these discretized spaces. Also the symplectic moduli space would be discretized to contain only n-tuples for which the symplectic invariants are numbers in the allowed algebraic extension of rationals. This would provide an abstract looking but actually very concrete operational approach to the discretization involving only areas of n-tuples as internal coordinates of symplectic equivalence classes of n-tuples. The best that one could achieve would be a formulation involving nothing below measurement resolution.

4. This picture based on elementary geometry might make sense also in the case of conformal symmetries. The angles associated with the vertices of the S^2 projection of n-polygon could define conformal invariants appearing in n-point functions and the algebraization of the corresponding phases would be an operational manner to introduce the space-time correlates for the roots of unity introduced at quantum level. In CP_2 degrees of freedom the projections of n-tuples to the homologically trivial geodesic sphere S^2 associated with the particular sector of CH would allow to define similar conformal invariants. This framework gives dimensionless areas (unit sphere is considered). p-Adic length scale hypothesis and hierarchy of Planck constants would bring in the fundamental units of length and time in terms of CP_2 length.

The recent view about M-matrix described in [22] is something almost unique determined by Connes tensor product providing a formal realization for the statement that complex rays of state space are replaced with \mathcal{N} rays where \mathcal{N} defines the hyper-finite sub-factor of type II_1 defining the measurement resolution. M -matrix defines time-like entanglement coefficients between positive and negative energy parts of the zero energy state and need not be unitary. It is

identified as square root of density matrix with real expressible as product of real and positive square root and unitary S-matrix. This S-matrix is what is measured in laboratory. There is also a general vision about how vertices are realized: they correspond to light-like partonic 3-surfaces obtained by gluing incoming and outgoing partonic 3-surfaces along their ends together just like lines of Feynman diagrams. Note that in string models string world sheets are non-singular as 2-manifolds whereas 1-dimensional vertices are singular as 1-manifolds. These ingredients we should be able to fuse together. So we try once again!

1. *Bottom-up* starting from vertices and propagators is the basic approach in the construction of n-point function in standard QFT. This approach does not work in quantum TGD. Symplectic and conformal field theories suggest that *top-down* approach replaces bottom-up approach in the construction. One starts from an n-point function and reduces it step by step to a vacuum expectation value of a 2-point function using fusion rules. Associativity becomes the fundamental dynamical principle in this process. Associativity in the sense of classical number fields has already shown its power and led to a hyperoctonionic formulation of quantum TGD promising a unification of various visions about quantum TGD [34].
2. Let us start from the representation of a zero energy state in terms of a causal diamond defined by future and past directed light-cones. Zero energy state corresponds to a quantum superposition of light-like partonic 3-surfaces each of them representing possible particle reaction. These 3-surfaces are very much like generalized Feynman diagrams with lines replaced by light-like 3-surfaces coming from the upper and lower light-cone boundaries and glued together along their ends at smooth 2-dimensional surfaces defining the generalized vertices.
3. It must be emphasized that the generalization of ordinary Feynman diagrammatics arises and conformal and symplectic QFTs appear only in the calculation of single generalized Feynman diagram. Therefore one could still worry about loop corrections. The fact that no integration over loop momenta is involved and there is always finite cutoff due to discretization together with top-down approach instead of bottom-up approach gives however good hopes that everything works. Note that this picture is in conflict with one of the earlier approaches based on positive energy ontology in which the hope was that only single generalized Feynman diagram could define the U-matrix thought to correspond to physical S-matrix at that time [36].
4. One can actually simplify things by identifying generalized Feynman diagrams as maxima of Kähler function with functional integration carried over perturbations around it. Thus one would have conformal field theory in both fermionic and configuration space degrees of freedom. The light-like time coordinate along light-like 3-surface is analogous to the complex coordinate of conformal field theories restricted to some curve. If it is possible continue the light-like time coordinate to a hyper-complex coordinate in the interior of 4-D space-time sheet, the correspondence with conformal field theories becomes rather concrete. Same applies to the light-like radial coordinates associated with the light-cone boundaries. At light-cone boundaries one can apply fusion rules of a symplectic QFT to the remaining coordinates. Conformal fusion rules are applied only to point pairs which are at different ends of the partonic surface and there are no conformal singularities since arguments of n-point functions do not co-incide. By applying the conformal and symplectic fusion rules one can eventually reduce the n-point function defined by the various fermionic and bosonic operators appearing at the ends of the generalized Feynman diagram to something calculable.
5. Finite measurement resolution defining the Connes tensor product is realized by the discretization applied to the choice of the arguments of n-point functions so that discretion is

not only a space-time correlate of finite resolution but actually defines it. No explicit realization of the measurement resolution algebra \mathcal{N} seems to be needed. Everything should boil down to the fusion rules and integration measure over different 3-surfaces defined by exponent of Kähler function and by imaginary exponent of Chern-Simons action. The continuation of the configuration space Clifford algebra for 3-surfaces with cm degrees of freedom fixed to a hyper-octonionic variant of gamma matrix field of super-string models defined in M^8 (hyper-octonionic space) and $M^8 \leftrightarrow M^4 \times CP_2$ duality leads to a unique choice of the points, which can contribute to n-point functions as intersection of M^4 subspace of M^8 with the counterparts of partonic 2-surfaces at the boundaries of light-cones of M^8 . Therefore there are hopes that the resulting theory is highly unique. Symplectic fusion algebra reduces to a finite algebra for each space-time surface if this picture is correct.

6. Consider next some of the details of how the light-like 3-surface codes for the fusion rules associated with it. The intermediate partonic 2-surfaces must be involved since otherwise the construction would carry no information about the properties of the light-like 3-surface, and one would not obtain perturbation series in terms of the relevant coupling constants. The natural assumption is that partonic 2-surfaces belong to future/past directed light-cone boundary depending on whether they are on lower/upper half of the causal diamond. Hyper-octonionic conformal field approach fixes the n_{int} points at intermediate partonic two-sphere for a given light-like 3-surface representing generalized Feynman diagram, and this means that the contribution is just N -point function with $N = n_{out} + n_{int} + n_{in}$ calculable by the basic fusion rules. Coupling constant strengths would emerge through the fusion coefficients, and at least in the case of gauge interactions they must be proportional to Kähler coupling strength since n-point functions are obtained by averaging over small deformations with vacuum functional given by the ex-

ponent of Kähler function. The first guess is that one can identify the spheres $S^2 \subset \delta M_{\pm}^4$ associated with initial, final and, and intermediate states so that symplectic n-points functions could be calculated using single sphere.

These findings raise the hope that quantum TGD is indeed a solvable theory. Even if one is not willing to swallow any bit of TGD, the classification of the symplectic QFTs remains a fascinating mathematical challenge in itself. A further challenge is the fusion of conformal QFT and symplectic QFT in the construction of n-point functions. One might hope that conformal and symplectic fusion rules can be treated separately.

2.8.4 Still more detailed view about the construction of M-matrix elements

After three decades there are excellent hopes of building an explicit recipe for constructing M-matrix elements but the devil is in the details.

1. Elimination of infinities and coupling constant evolution

The elimination of infinities would follow from the symplectic QFT part of the theory. The symplectic contribution to n-point functions vanishes when two arguments co-incide. The UV cancellation mechanism has nothing to do with the finite measurement resolution which corresponds to the size of the causal diamonds inside which the space-time sheets representing radiative corrections are. There is also IR cutoff due to the presence of largest causal diamond.

One can decompose the radiative corrections two two types. First kind of corrections appear both at the level of positive/and negative energy parts of zero energy states. Second kind of corrections appear at the level of interactions between them. This decomposition is standard in quantum field theories and corresponds to the renormalization constants of fields *resp.* renormalization of coupling constants. The corrections due to the increase of measurement resolution in time comes as very specific corrections to positive and negative energy states involving gluing of smaller causal diamonds to the upper and lower

boundaries of causal diamonds along any radial light-like ray. The radiative corresponds to the interactions correspond to the addition of smaller causal diamonds in the interior of the larger causal diamond. Scales for the corrections come as scalings in powers of 2 rather than as continuous scaling of measurement resolution.

2. Conformal symmetries

The basic questions are the following ones. How hyper-octonionic/-quaternionic/-complex super-conformal symmetry relates to the super-canonical conformal symmetry at the imbedding space level and the super Kac-Moody symmetry associated with the light-like 3-surfaces? How do the dual $HO = M^8$ and $H = M^4 \times CP_2$ descriptions (number theoretic compactification) relate?

Concerning the understanding of these issues, the earlier construction of physical states poses strong constraints [21].

1. The state construction utilizes both super-canonical and super Kac-Moody algebras. Super-canonical algebra has negative conformal weights and creates tachyonic ground states from which Super Kac-Moody algebra generates states with non-negative conformal weight determining the mass squared value of the state. The commutator of these two algebras annihilates the physical states. This requires that both super conformal algebras must allow continuation to hyper-octonionic algebras, which are independent.
2. The light-like radial coordinate at δM_{\pm}^4 can be continued to a hyper-complex coordinate in M_{\pm}^2 defined the preferred commutative plane of non-physical polarizations, and also to a hyper-quaternionic coordinate in M_{\pm}^4 . Hence it would seem that super-canonical algebra can be continued to an algebra in M_{\pm}^2 or perhaps in the entire M_{\pm}^4 . This would allow to continue also the operators G , L and other super-canonical operators to operators in hyper-quaternionic M_{\pm}^4 needed in stringy perturbation theory.
3. Also the super KM algebra associated with the

light-like 3-surfaces should be continueable to hyper-quaternionic M_{\pm}^4 . Here $HO - H$ duality comes in rescue. It requires that the preferred hyper-complex plane M^2 is contained in the tangent plane of the space-time sheet at each point, in particular at light-like 3-surfaces. We already know that this allows to assign a unique space-time surface to a given collection of light-like 3-surfaces as hyper-quaternionic 4-surface of HO hypothesized to correspond to (an obviously preferred) extremal of Kähler action. An equally important implication is that the light-like coordinate of X^3 can be continued to hyper-complex coordinate M^2 coordinate and thus also to hyper-quaternionic M^4 coordinate.

4. The four-momentum appears in super generators G_n and L_n . It seems that the formal Fourier transform of four-momentum components to gradient operators to M_{\pm}^4 is needed and defines these operators as particular elements of the CH Clifford algebra elements extended to fields in imbedding space.

3. What about stringy perturbation theory?

The analog of stringy perturbation theory does not seem only a highly attractive but also an unavoidable outcome since a generalization of massless fermionic propagator is needed. The inverse for the sum of super Kac-Moody and super-canonical super-Virasoro generators $G(L)$ extended to an operator acting on the difference of the M^4 coordinates of the end points of the propagator line connecting two partonic 2-surfaces should appear as fermionic (bosonic) propagator in stringy perturbation theory. Virasoro conditions imply that only G_0 and L_0 appear as propagators. Momentum eigenstates are not strictly speaking possible since since discretization is present due to the finite measurement resolution. One can however represent these states using Fourier transform as a superposition of momentum eigenstates so that standard formalism can be applied.

Symplectic QFT gives an additional multiplicative contribution to n-point functions and there would be also braiding S-matrices involved with the propagator lines in the case that partonic 2-surface carriers

more than 1 point. This leaves still modular degrees of freedom of the partonic 2-surfaces describable in terms of elementary particle vacuum functionals and the proper treatment of these degrees of freedom remains a challenge.

4. *What about non-hermiticity of the CH super-generators carrying fermion number?*

TGD represents also a rather special challenge, which actually represents the fundamental difference between quantum TGD and super string models. The assignment of fermion number to CH gamma matrices and thus also to the super-generator G is unavoidable. Also M^4 and H gamma matrices carry fermion number. This has been a long-standing interpretational problem in quantum TGD and I have been even ready to give up the interpretation of four-momentum operator appearing in G_n and L_n as actual four-momenta. The manner to get rid of this problem would be the assumption of Majorana property but this would force to give up the interpretation of different imbedding space chiralities in terms of conserved lepton and quark numbers and would also lead to super-string theory with critical dimension 10 or 11. A further problem is how to obtain amplitudes which respect fermion number conservation using string perturbation theory if $1/G = G^\dagger/L_0$ carries fermion number.

The recent picture does not leave many choices so that I was forced to face the truth and see how everything falls down to this single nasty detail! It became as a total surprise that gamma matrices carrying fermion number do not cause any difficulties in zero energy ontology and make sense even in the ordinary Feynman diagrammatics.

1. Non-hermiticity of G means that the center of mass terms CH gamma matrices must be distinguished from their Hermitian conjugates. In particular, one has $\gamma_0 \neq \gamma_0^{agger}$. One can interpret the fermion number carrying M^4 gamma matrices of the complexified quaternion space.
2. One might think that $M^4 \times CP_2$ gamma matrices carrying fermion number is a catastrophe but this is not the case in massless the-

ory. Massless momentum eigen states can be created by the operator $p^k \gamma_k^\dagger$ from a vacuum annihilated by gamma matrices and satisfying massless Dirac equation. The conserved fermion number defined by the integral of $\bar{\Psi} \gamma^0 \Psi$ over 3-space gives just its standard value. A further experimentation shows that Feynman diagrams with non-hermitian gamma matrices give just the standard results since fermionic propagator and boson-emission vertices give compensating fermion numbers.

3. If the theory would contain massive fermions or a coupling to a scalar Higgs, a catastrophe would result. Hence ordinary Higgs mechanism is not possible in this framework. Of course, also the quantization of fermions is totally different. In TGD fermion mass is not a scalar in H . Part of it is given by CP_2 Dirac operator, part by p-adic thermodynamics for L_0 , and part by Higgs field which behaves like vector field in CP_2 degrees of freedom, so that the catastrophe is avoided.
4. In zero energy ontology zero energy states are characterized by M-matrix elements constructed by applying the combination of stringy and symplectic Feynman rules and fermionic propagator is replaced with its super-conformal generalization reducing to an ordinary fermionic propagator for massless states. The norm of a single fermion state is given by a propagator connecting positive energy state and its conjugate with the propagator G_0/L_0 and the standard value of the norm is obtained by using Dirac equation and the fact that Dirac operator appears also in G_0 .
5. The hermiticity of super-generators G would require Majorana property and one would end up with superstring theory with critical dimension $D = 10$ or $D = 11$ for the imbedding space. Hence the new interpretation of gamma matrices, proposed already years ago, has very profound consequences and convincingly demonstrates that TGD approach is indeed internally consistent.

2.8.5 Symplectic fusion algebra and Feynman operad

Super-canonical transformations (ch. *Construction of Configuration Space Kähler Geometry from Symmetry Principles: Part II* of [2]) distinguish quantum TGD from string model and the resulting symplectic fusion algebras realize algebraically the absence of ultraviolet divergences predicted by very general arguments (Kähler function is non-local functional of 3-surface and Gaussian and metric determinants cancel each other). Algebraically this corresponds to the nilpotency ($x^2 = 0$) of the generating elements of the necessarily discrete symplectic fusion algebras forming an infinite hierarchy labeled by all possible trees. The addition of a tree at the end of given branch means improvement of measurement resolution replacing single strand of braid with a braid. Symplecto-conformal fusion algebras [23] form an operad [82] like structure meaning the existence of homomorphisms between the original algebra and that obtained by improving measurement resolution. These homomorphisms characterize algebraically what happens as the measurement resolution is increased or reduced locally. Symplectic transformations of $\delta M_{\pm}^4 \times CP_2$ act as gauge symmetries mapping to each other equivalent triangulations of the sphere defining representations of symplectic fusion algebras.

The structure constants of the symplectic fusion algebra are products of three roots of unity (this realizes number theoretical universality) and have physical interpretation as plane wave factors. Also the representations of color quantum numbers in this manner are possible. Momentum conservation modulo measurement resolution means that the product of the phase factors associated with the lines arriving to the vertex equals to unity. At the continuum limit exact momentum conservation emerges and usual conformal N-point functions represent vertices.

3 Some applications

Quantum TGD has developed by applying the guess for quantum TGD and applications range from el-

ementary particle physics to cosmology and involve also biology and neuroscience.

The concept of many-sheeted space-time leads to a completely new interpretation of the structures that we see around us and has forced to accept the presence of new physics in all scales in TGD Universe. p-Adic mass calculations represent an application of super-conformal invariance in TGD based sense [37, 38, 39] and the theory predicts several important predictions distinguishing TGD from standard model. For instance, hadronic mass calculations lead to precise predictions of hadron masses on basis of new "super-canonical" degrees of freedom not present in QCD [40]. New scaled variants of hadronic physics are predicted [41] as well as analogs of hadronic physics with quarks replaced by colored excitations of leptons [42].

Nuclear string model [44] predicts a lot of new nuclear physics and provides also a model of cold fusion and a new view about the origin of heavier elements. A new topological view about chemical bond and condensed matter emerges with the proposal that long ranged exotic variants of weak and color interactions are essential for understanding of, say, the incompressibility of solid and liquid states [45]. The hierarchy of Planck constants [26] has led to very powerful predictions including a model for bio-catalysis [62].

Zero energy ontology and the new vision about time inspire a new vision about memory and about the realization of intentional action, and inspire also the notion of remote metabolism based on the universality of metabolic energy quanta as increments of zero point kinetic energy in the transfer of particles between space-time sheets characterized by different p-adic primes [62].

Topological quantization implying that any physical system has a "personal" field body is of special relevance in biology and TGD inspired neuroscience [62]. Magnetic body is identified as an intentional agent using biological body as a sensory receptor and motor instrument. This predicts generalization of genetic code predicting hierarchy of coherent gene expressions at level of cell, organs, organism, and even populations and relying on hierarchy of Planck constants and magnetic flux sheets traversing through DNA strands [56]. Evolutionary leaps can be un-

derstood as increases of the largest value of Planck constant in "personal" hierarchy of Planck constants characterizing organism. Wormhole magnetic flux tubes define the strands of braids making possible for DNA and also other bio-molecules to act as topological quantum quantum computer [57]. Models for the evolution of genetic code [58], for protein folding and catalyst action [59] and for nerve pulse and EEG [60, 61] emerge involving in essential manner the hierarchy of Planck constants.

Despite that TGD does not reduce to a string model, string like objects play a key role in applications: mention only cosmic string based primordial cosmology [30, 29] and the explanation for magnetic fields appearing in all astrophysical scales in terms of magnetic flux tubes. The hierarchy of Planck constants revolutionizes the view about quantum gravitation and dark matter [31, 32] and the Universe is predicted to be macroscopic quantum system in all scales at some levels of dark matter hierarchy. The replacement of the smooth cosmic expansion with an expansion taking place in discrete jumps increasing the value of Planck constant for the relevant level of dark matter hierarchy leads to quite dramatic predictions [32] and many of them have already found empirical support: mention only the TGD variant of the theory of Expanding Earth relevant also for biology [58].

The discussion of all these applications would take too much space and in the following only some representative examples are discussed.

3.1 p-Adic mass calculations

p-Adic mass calculations represent second application [38, 37, 39, 40, 41]. Inertial four-momentum for a given space-time sheet can be understood in TGD framework as a temporal average of non-conserved gravitational four-momentum expressible as a Noether charge associated with partons so that Equivalence Principle is satisfied only in a weak form. An essential assumption is that CP_2 Kähler gauge potential has a pure gauge component $A_a = \text{constant}$ in the direction of light-cone proper time a : this means that M_{\pm}^4 and CP_2 degrees of freedom are not completely uncorrelated.

This explains the generation of inertial mass and p-adic thermodynamics is justified by the randomness of the motion of partonic 2-surfaces restricted only by light-likeness of the orbit. It is essential that the conformal symmetries associated with the light-like coordinates of parton and light-cone boundary are not gauge symmetries but dynamical symmetries.

In p-adic thermodynamics scaling generator L_0 having conformal weights as its eigen values replaces energy and Boltzmann weight $\exp(H/T)$ is replaced by p^{L_0/T_p} . The quantization $T_p = 1/n$ of conformal temperature and thus quantization of mass squared scale is implied by number theoretical existence of Boltzmann weights. p-Adic length scale hypothesis states that primes $p \simeq 2^k$, k integer. A stronger hypothesis is that k is prime (in particular Mersenne prime or Gaussian Mersenne) makes the model very predictive and fine tuning is not possible.

The basic mystery number of elementary particle physics defined by the ratio of Planck mass and proton mass follows thus from number theory once CP_2 radius is fixed to about 10^4 Planck lengths. Mass scale becomes additional discrete variable of particle physics so that there is not more need to force top quark and neutrinos with mass scales differing by 12 orders of magnitude to the same multiplet of gauge group. Electron, muon, and tau correspond to Mersenne prime $k = 127$ (the largest non-super-astrophysical Mersenne), and Mersenne primes $k = 113, 107$. Intermediate gauge bosons and photon correspond to Mersenne M_{89} , and graviton to M_{127} .

The value of k for quark can depend on hadronic environment [40] and this would produce precise mass formulas for low energy hadrons. This kind of dependence conforms also with the indications that neutrino mass scale depends on environment [84]. Amazingly, the biologically most relevant length scale range between 10 nm and 4 μm contains four Gaussian Mersennes $(1 + i)^n - 1$, $n = 151, 157, 163, 167$ and scaled copies of standard model physics in cell length scale could be an essential aspect of macroscopic quantum coherence prevailing in cell length scale.

p-Adic mass thermodynamics is not quite enough: also Higgs boson is needed and wormhole contact carrying fermion and anti-fermion quantum numbers at

the light-like wormhole throats is excellent candidate for Higgs [38]. The coupling of Higgs to fermions can be small and induce only a small shift of fermion mass: this could explain why Higgs has not been observed. Also the Higgs contribution to mass squared can be understood thermodynamically if identified as absolute value for the thermal expectation value of the eigenvalues of the modified Dirac operator having interpretation as complex square root of conformal weight.

The original belief was that only Higgs corresponds to wormhole contact. The assumption that fermion fields are free in the conformal field theory applying at parton level forces to identify all gauge bosons as wormhole contacts connecting positive and negative energy space-time sheets [38]. Fermions correspond to topologically condensed CP_2 type extremals with single light-like wormhole throat. Gravitons are identified as string like structures involving pair of fermions or gauge bosons connected by a flux tube. Partonic 2-surfaces are characterized by genus which explains family replication phenomenon and an explanation for why their number is three emerges [37]. Gauge bosons are labeled by pairs (g_1, g_2) of handle numbers and can be arranged to octet and singlet representations of the resulting dynamical $SU(3)$ symmetry. Ordinary gauge bosons are $SU(3)$ singlets and the heaviness of octet bosons explains why higher boson families are effectively absent. The different character of bosons could also explain why the p-adic temperature for bosons is $T_p = 1/n < 1$ so that Higgs contribution to the mass dominates.

3.2 Cosmology and astrophysics

The first applications of TGD were to astrophysics [31, 32] and cosmology [30].

3.2.1 Cosmology

In cosmology Lorentz invariance of space-time sheet implies Robertson-Walker cosmology and the absence of finite horizons. The imbeddability required for R-W cosmologies allows cosmologies with critical or over-critical mass density only for a finite duration of cosmic time after which a phase transition to

a sub-critical cosmology occurs. TGD counterpart for inflationary cosmology is quantum critical cosmology in which quantum fluctuations in arbitrarily long time and length scales give rise to scaled invariant fractal spectrum of density fluctuations. Many-sheeted space-time implies many-sheeted cosmology with a Russian doll like cosmologies within cosmologies structure.

Dark energy corresponds to magnetic flux quanta carrying dark matter and fractal hierarchy of magnetic flux quanta is in a key role. Dark matter hierarchy predicts also the existence quantization axes in astrophysical and cosmological length scales: their presence should be visible and could relate to the anomalous behavior of cosmic microwave background [89]. Also anomalously low dissipation rates in astrophysical and cosmological length scales due to large values of Planck constant are expected. The anomalously low dissipation of solar magnetic field might be one example of this.

3.2.2 Quantum coherence in astrophysical length scales

TGD leads also to a model for rotating star predicting dynamo-like structure and concentration of mass on spherical shells at given space-time sheet [28]. Dark matter becomes a key player in the dynamics of planetary systems and dictates the dynamics of visible matter via gravitational binding. The possibility of huge values of Planck constants for dark matter leads to a hydrogen atom like model for planetary systems suggested first by Nottale [83], and the fits for the radii of planetary orbits (also those of exoplanets) and mass ratios of planets in solar system, based on number theoretically preferred values of Planck constant given in terms of integers n characterizing polygons constructible only ruler and compass, are rather accurate [31]. It should be emphasized that astrophysical Bohr rules can be formulated in General Coordinate invariant and Lorentz invariant manner in TGD framework.

Quantum criticality of TGD Universe is mathematically analogous to quantum chaos. This inspires the idea that chaotic quantum states and scattering could be realized in astrophysical length and time

scales. Dark matter structures consisting of rings and spokes should become visible in (say) galactic collisions and ring galaxies, cartwheel galaxies, and polar ring galaxies are examples of predicted structures [32].

In this picture cosmic expansion as a smooth expansion of space-time is replaced by a sequence of phase transitions increasing gravitational Planck constant and thus size scale of space-time sheets and completely analogous to atomic and molecular quantum transitions. This expansion takes place in all length scales and various anomalies of recent day cosmology, in particular the acceleration anomaly requiring non-vanishing cosmological constant, find natural explanation [32]. It occurs also in planetary scale and the Expanding Earth Theory constructed to explain the fact that continents would fit together if Earth's radius had radius half of the recent radius could understand as reflecting the occurrence of this kind of phase transition inducing also Cambrian explosion which is one of the mysteries of evolutionary biology [32].

3.3 Hierarchy of scaled variants of standard model physics

TGD predicts an infinite hierarchy of scaled up variants of elementary particle physics which means the failure of reductionism but with precise quantitative predictions made possible by fractal scaling arguments. p-Adic length scale hierarchy suggests hierarchy of physics with mass spectra deducible by simple scaling arguments. Hierarchy of dark matters predicts a hierarchy of zoomed up variants of ordinary elementary particles with identical mass spectra. M_{89} -copy of ordinary hadronic physics characterized by M_{107} [41] is an especially interesting possibility concerning LHC. The copies of hadronic physics (say for M_{61}) could also explain the cosmic rays with anomalously high energies.

The idea about dark matter might have applications already in nuclear physics and even hadron physics might involve larger values of Planck constant. Valence quarks could correspond to some low, perhaps the lowest level $q = \exp(in\pi/3)$, $n = 3$, for dark matter hierarchy. Note that corresponding

group is Z_3 and corresponds to SU(3) by McKay correspondence (flavor SU(3) of Gell-Mann perhaps?).

The model of nucleus as entangled nuclear string with nucleons connected by color flux tubes containing at their ends dark exotic quark and anti-quark with mass scale of electron emerges naturally [43, 44] and predicts with surprising precision ground state binding energies as well as the energies associated with giant resonances. The recently observed dependence of nuclear reaction rates on electronic environment [85] and claims for cold fusion [86] and nuclear transmutations claimed in living matter [87] could be understood in terms of many-sheeted space-time concept with many-sheeted-ness allowing to circumvent Coulomb barrier [43, 44]. The model of cold fusion inspired by the nuclear string model leads to a rich spectrum of predictions, one of them being that elements heavier than Lithium might have been generated in the interstellar space besides stellar interiors. The completely unexpected discovery that the abundances of heavier elements in objects at distance of about 10 billion years are essentially the same as in solar system [88], supports this view. The anomalous variation of nuclear decay rates [90, 91, 92, 93] in the time scale of year and correlation with the distance from Sun and also the evidence for the variation of rates with solar flares can be understood understood if X rays from Sun induce transitions from ground states of nucleus to exotic states containing charged color bonds: the energy scale is $\alpha_{em}m$ and 10 keV if mass scale corresponds to MeV. GSI anomaly [94] in which certain nuclear rates vary with 7 second period can be understood as time-dependent charge entanglement between nucleon and quark at the end of color bond.

3.4 Quantum TGD and biology

Many-sheeted space-time and dark matter as phases with large Planck constant has the most natural applications to condensed matter physics and biology and the discrete rotational symmetries associated with given value of M^4 Planck constant serve as the unique signature. A model of high T_c superconductivity as a quantum critical phenomenon involving electrons with $\hbar = 2^{11}\hbar_0$ with zoomed up

Compton length emerges. The overlap criterion for the formation of Cooper pairs is satisfied and gap energy and critical temperature are scaled up correspondingly [51, 52, 53]. Color interactions in zoomed up length scales are essential for the model of exotic Coopers with non-vanishing spin which are present besides large \hbar variants of BCS type Cooper pairs.

Dropping of particles to larger space-time sheets with a liberation of zero point kinetic energy as a metabolic energy leads to the idea of universal metabolic energy quanta [55]. The new view about energy and time has important implications. Phase conjugate photons with negative energies propagating into geometric past provide a mechanism for a communication with the geometric past: the mechanisms of remote metabolism ("quantum credit card") and memory recall as this communication are possible applications. Time-like entanglement represented by S-matrix in zero energy ontology with the geometric past provides a second mechanism of long term memory based on sharing of mental images with the brain of geometric past [49].

One important implication of many-sheeted space-time concept is the notion of magnetic/field body. The classical field configurations associated with a given physical system are topologically quantized so that it is possible to assign to the system a field identity, "field body". The notion of magnetic body is in a key role in the theory of living systems, in particular, in the model of EEG and its generalization to a hierarchy of EEGs [61]. Also GEG corresponding to gluons and ZEG and WEG corresponding to exotic dark Z^0 and W bosons with latter making possible charge entanglement in macroscopic length scales, are possible. Large value of Planck constant implying that EEG photons have energies above thermal energy would explain why EEG photons correlate with brain function and contents of consciousness. The strange findings of Libet [96] about time delays of active and passive aspects of consciousness could be seen as a support for the notion of magnetic body [61].

The magnetic flux tubes carrying supra currents of dark charged particles explain the strange findings about the behavior of ionic currents through cell membrane. As a matter fact, dominant part of bi-

ologically important ions would be dark matter and be visible only through classical gauge interactions. These flux tubes also play a key role in TGD inspired model of nerve pulse explaining the strange findings about nerve pulse predicting automatically also EEG and explaining the synchrony of EEG and kHz oscillations. One can also understand the DC currents of Becker and magnetic body allows to understand for the notions of ancient chinese medicine (chi, meridians, and acupuncture points) in terms of magnetic body. In the model of DNA as topological quantum computer (tqc) magnetic flux tubes connecting DNA nucleotides to the lipids of nuclear membrane and cell membranes define the strands of braids whose braiding codes for tqc programs. The phase transitions reducing Planck constant induce shortening of magnetic flux tubes connecting bio-molecules: this could explain the miraculous ability of bio-molecules to find each other.

4 Where are we now?

These three decades have made it clear to me how slow the progress in physics really is and how small the contribution of individual is bound to be. I have been able to identify these visions about basic principles and perhaps even demonstrate that M-matrix exists and is unique to a high degree. About how to calculate M-matrix I cannot say much: I simply lack the technical know-how about HFFs and I am too old to learn it. I can only hope that some young mathematically oriented colleague becomes convinced that this strange jungle of ideas that I call TGD might provide inspiration if not anything else. The mathematical work should be however guided by a continual application of already existing theory in order to avoid the degeneration to a production of dead formalism. Also the tension between different visions should continue to serve as a very effective idea generator.

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