Configuration Space Spinor Structure

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Abstract

There are three separate approaches to the challenge of constructing WCW Kähler geometry and spinor structure. The first approach relies on a direct guess of Kähler function. Second approach relies on the construction of Kähler form and metric utilizing the huge symmetries of the geometry needed to guarantee the mathematical existence of Riemann connection. The third approach discussed in this chapter relies on the construction of spinor structure based on the hypothesis that complexified WCW gamma matrices are representable as linear combinations of fermionic oscillator operator for the second quantized free spinor fields at space-time surface and on the geometrization of super-conformal symmetries in terms of spinor structure. This implies a geometrization of fermionic statistics.

The basic philosophy is that at fundamental level the construction of WCW geometry reduces to the second quantization of the induced spinor fields using Dirac action. This assumption is parallel with the bosonic emergence stating that all gauge bosons are pairs of fermion and antifermion at opposite throats of wormhole contact. Vacuum function is identified as Dirac determinant and the conjecture is that it reduces to the exponent of Kähler function. In order to achieve internal consistency induced gamma matrices appearing in Dirac operator must be replaced by the modified gamma matrices defined uniquely by Kähler action and one must also assume that extremals of Kähler action are in question so that the classical space-time dynamics reduces to a consistency condition. This implies also super-symmetries and the fermionic oscillator algebra at partonic 2-surfaces has intepretation as $\mathcal{N} = \infty$ generalization of space-time super-symmetry algebra different however from standard SUSY algebra in that Majorana spinors are not needed. This algebra serves as a building brick of various super-conformal algebras involved.

The requirement that there exist deformations giving rise to conserved Noether charges requires that the preferred extremals are critical in the sense that the second variation of the Kähler action vanishes for these deformations. Thus Bohr orbit property could correspond to criticality or at least involve it.

Quantum classical correspondence demands that quantum numbers are coded to the properties of the preferred extremals given by the Dirac determinant and this requires a linear coupling to the conserved quantum charges in Cartan algebra. Effective 2-dimensionality allows a measurement interaction term only in 3-D Chern-Simons Dirac action assignable to the wormhole throats and the ends of the space-time surfaces at the boundaries of CD. This allows also to have physical propagators reducing to Dirac propagator not possible without the measurement interaction term. An essential point is that the measurement interaction corresponds formally to a gauge transformation for the induced Kähler gauge potential. If one accepts the weak form of electric-magnetic duality Kähler function reduces to a generalized Chern-Simons term and the effect of measurement interaction term to Kähler function reduces effectively to the same gauge transformation.

The basic vision is that WCW gamma matrices are expressible as super-symplectic charges at the boundaries of CD. The basic building brick of WCW is the product of infinite-D symmetric spaces assignable to the ends of the propagator line of the generalized Feynman diagram. WCW Kähler metric has in this case "kinetic" parts associated with the ends and "interaction" part between the ends. General expressions for the super-counterparts of WCW flux Hamiltoniansand for the matrix elements of WCW metric in terms of their anticommutators are proposed on basis of this picture.

1 Introduction

Quantum TGD should be reducible to the classical spinor geometry of the configuration space. In particular, physical states should correspond to the modes of the configuration space spinor fields. The immediate consequence is that configuration space spinor fields cannot, as one might naively expect, be carriers of a definite spin and unit fermion number. Concerning the construction of the configuration space spinor structure there are some important clues.

1.1 Geometrization of fermionic statistics in terms of configuration space spinor structure

The great vision has been that the second quantization of the induced spinor fields can be understood geometrically in terms of the configuration space spinor structure in the sense that the anti-commutation relations for configuration space gamma matrices require anti-commutation relations for the oscillator operators for free second quantized induced spinor fields.

1. One must identify the counterparts of second quantized fermion fields as objects closely related to the configuration space spinor structure. [5] has as its basic field the anti-commuting field $\Gamma^k(x)$, whose Fourier components are analogous to the gamma matrices of the configuration space and which behaves like a spin 3/2 fermionic field rather than a vector field. This suggests that the are analogous to spin 3/2 fields and therefore expressible in terms of the fermionic oscillator operators so that their naturally derives from the anti-commutativity of the fermionic oscillator operators.

   As a consequence, configuration space spinor fields can have arbitrary fermion number and there would be hopes of describing the whole physics in terms of configuration space spinor field. Clearly, fermionic oscillator operators would act in degrees of freedom analogous to the spin degrees of freedom of the ordinary spinor and bosonic oscillator operators would act in degrees of freedom analogous to the 'orbital' degrees of freedom of the ordinary spinor field.

2. The classical theory for the bosonic fields is an essential part of the configuration space geometry. It would be very nice if the classical theory for the spinor fields would be contained in the definition of the configuration space spinor structure somehow. The properties of the associated with the induced spinor structure are indeed very physical. The modified massless Dirac equation for the induced spinors predicts a separate conservation of baryon and lepton numbers. Contrary to the long held belief it seems that covariantly constant right handed neutrino does not generate . The differences between quarks and leptons result from the different couplings to the CP_2 Kähler potential. In fact, these properties are shared by the solutions of massless Dirac equation of the imbedding space.

3. Since TGD should have a close relationship to the ordinary quantum field theories it would be highly desirable that the second quantized free induced spinor field would somehow appear in the definition of the configuration space geometry. This is indeed true if the complexified configuration space gamma matrices are linearly related to the oscillator operators associated with the second quantized induced spinor field on the space-time surface and its boundaries. There is actually no deep reason forbidding the gamma matrices of the configuration space to be spin half odd-integer objects whereas in the finite-dimensional case this is not possible in general. In fact, in the finite-dimensional case the equivalence of the spinorial and vectorial vielbeins forces the spinor and vector representations of the vielbein group $SO(D)$ to have same dimension and this is possible for $D = 8$-dimensional Euclidian space only. This coincidence might explain the success of 10-dimensional super string models for which the physical degrees of freedom effectively correspond to an 8-dimensional Euclidian space.

4. It took a long time to realize that the ordinary definition of the gamma matrix algebra in terms of the anti-commutators $\{\gamma_A, \gamma_B\} = 2g_{AB}$ must in TGD context be replaced with

   $$\{\gamma_A^\dagger, \gamma_B\} = iJ_{AB} \quad ,$$

   where J_{AB} denotes the matrix elements of the Kähler form of the configuration space. The presence of the Hermitian conjugation is necessary because configuration space gamma matrices carry fermion number. This definition is numerically equivalent with the standard one in the complex coordinates. The realization of this delicacy is necessary in order to understand how the square of the configuration space Dirac operator comes out correctly.

5. TGD as a generalized number theory vision leads to the understanding of how the second quantization of the induced spinor fields should be carried out and space-time conformal symmetries allow to explicitly solve the Dirac equation associated with the modified Dirac action in the interior and at the 3-D light like causal determinants. An essentially new element is the notion of number theoretic braid forced by the fact that the modified Dirac operator allows only finite number of generalized eigen modes so that the number of fermionic oscillator operators is finite. As a consequence, anticommutation relations can be satisfied only for a finite set of points defined by the number theoretic braid, which is uniquely identifiable. The interpretation is in terms of finite measurement resolution. The finite Clifford algebra spanned by the fermionic oscillator operators is interpreted as the factor space $\mathcal{M}/\mathcal{N}$ of infinite hyper-finite factors of type

II_1 defined by configuration space Clifford algebra $\mathcal{N}$ and included Clifford algebra $\mathcal{M} \subset \mathcal{N}$ interpreted as the characterizer of the finite measurement resolution. Note that the finite number of eigenvalues guarantees that Dirac determinant identified as the exponent of Kähler function is finite. Finite number of eigenvalues is also essential for number theoretic universality.

1.2 Modified Dirac equation for induced classical spinor fields

The earlier approach to the definition of the configuration space spinor structure relied on the second quantized ordinary massless Dirac action for the induced spinors. This action had some anomalous looking features. The first anomaly was the appearance of the effective tachyonic mass term proportional to the trace of the second fundamental form vanishing only for minimal surfaces. The breaking of $N = 2$ super symmetry generated by right-handed neutrinos for other than minimal surfaces was the second anomalous feature. It became also clear that the divergences of the fermionic isometry currents can have a non-vanishing c-number anomaly unless one varies Dirac action also with respect to the configuration space coordinates. This anomaly obviously might destroy the definition of the configuration space spinor structure.

The vision about quantum TGD as a generalized number theory [26, 27, 25] comes in rescue here. One of its outcomes was the realization that, in order to achieve exact super-symmetry, one must modify Dirac action so that its variation with respect to the imbedding space coordinates gives the field equations derivable from the action principle in question. By taking the modified Dirac action as the fundamental action, one can identify vacuum functional as the Dirac determinant. If this determinant equals to exponent of Kähler action for the preferred extremal containing partonic 3-surfaces, one can predict even the value of the Kähler coupling constant.

1.2.1 Chern-Simons - or Kähler Dirac action?

Two alternative choices represented themselves as candidates for the modified Dirac action: either the 3-D Chern-Simons Dirac action or 4-D Kähler action. Eventually came the realization that the addition of a measurement interaction term to either Chern-Simons action or Kähler action is needed to resolve a bundle of conceptual problems. It took still some time to conclude that Kähler action with instanton term is the correct choice since the measurement interaction term assigned to Chern-Simons-Dirac action creates more problems than it solves.

1. *Basic implications*

1. A correlation between 4-D geometry of space-time sheet and quantum numbers is achieved by the identification of exponent of Kähler function as Dirac determinant making possible the entanglement of classical degrees of freedom in the interior of space-time sheet with quantum numbers.

2. Cartan algebra plays a key role not only at quantum level but also at the level of space-time geometry since quantum critical conserved currents vanish for Cartan algebra of isometries and the measurement interaction terms giving rise to conserved currents are possible only for Cartan algebras. Furthermore, modified Dirac equation makes sense only for eigen states of Cartan algebra generators. The hierarchy of Planck constants realized in terms of the book like structure of the generalized imbedding space assigns to each CD (causal diamond) preferred Cartan algebra: in case of Poincare algebra there are two of them corresponding to linear and cylindrical M^4 coordinates.

3. Quantum holography and dimensional reduction hierarchy in which partonic 2-surface defined fermionic sources for 3-D fermionic fields at light-like 3-surfaces Y_l^3 in turn defining fermionic sources for 4-D spinors find an elegant realization. Effective 2-dimensionality is achieved if the replacement of light-like wormhole throat X_l^3 with light-like 3-surface Y_l^3 "parallel" with it in the definition of Dirac determinant corresponds to the $U(1)$ gauge transformation $K \rightarrow K + f + \overline{f}$ for Kähler function of WCW so that WCW Kähler metric is not affected. Here f is holomorphic function of WCW ("world of classical worlds") complex coordinates and arbitrary function of zero mode coordinates.

4. An elegant description of the interaction between super-conformal representations realized at partonic 2-surfaces and dynamics of space-time surfaces is achieved since the values of Cartan charges are feeded to the 3-D Dirac equation which also receives mass term at the same time. Almost topological QFT at wormhole throats results at the limit when four-momenta vanish: this is in accordance with the original vision about TGD as almost topological QFT.

5. A detailed view about the physical role of quantum criticality results. Quantum criticality fixes the values of Kähler coupling strength as the analog of critical temperature. Quantum criticality implies that second variation of Kähler action vanishes for critical deformations and the existence of conserved current except in the case of Cartan algebra of isometries. Quantum criticality allows to fix the values of couplings appearing in the measurement interaction by using the condition $K \rightarrow K + f + \overline{f}$. p-Adic coupling constant evolution can be understood also and corresponds to scale hierarchy for the sizes of causal diamonds (CDs).

6. The inclusion of imaginary instanton term to the definition of the modified gamma matrices is not consistent with the conjugation of the induced spinor fields. Measurement interaction can be however assigned to both Kähler action and its instanton term. CP breaking, irreversibility and the space-time description of dissipation are closely related and the CP and T oddness of the instanton part of the measurement interaction term could provide first level description for dissipative effects. It must be however emphasized that the mere addition of instanton term to Kähler function could be enough.

7. A radically new view about matter antimatter asymmetry based on zero energy ontology emerges and one could understand the experimental absence of antimatter as being due to the fact antimatter corresponds to negative energy states. The identification of bosons as wormhole contacts is the only possible option in this framework.

8. Almost stringy propagators and a consistency with the identification of wormhole throats as lines of generalized Feynman diagrams is achieved. The notion of bosonic emergence leads to a long sought general master formula for the M-matrix elements. The counterpart for fermionic loop defining bosonic inverse propagator at QFT limit is wormhole contact with fermion and cutoffs in mass squared and hyperbolic angle for loop momenta of fermion and antifermion in the rest system of emitting boson have precise geometric counterpart.

2. Hyper-quaternionicity and quantum criticality

The conjecture that quantum critical space-time surfaces are hyper-quaternionic in the sense that the modified gamma matrices span a quaternionic subspace of complexified octonions at each point of the space-time surface is consistent with what is known about preferred extremals. The condition that both the modified gamma matrices and spinors are quaternionic at each point of the space-time surface leads to a precise ansatz for the general solution of the modified Dirac equation making sense also in the real context. The octonionic version of the modified Dirac equation is very simple since $SO(7,1)$ as vielbein group is replaced with G_2 acting as automorphisms of octonions so that only the neutral Abelian part of the classical electro-weak gauge fields survives the map.

Octonionic gamma matrices provide also a non-associative representation for the 8-D version of Pauli sigma matrices and encourage the identification of 8-D twistors as pairs of octonionic spinors conjectured to be highly relevant also for quantum TGD. Quaternionicity condition implies that octo-twistors reduce to something closely related to ordinary twistors.

1.2.2 Super-conformal symmetries of modified Dirac action

The modified Dirac equation allows large number of super-conformal gauge symmetries as zero modes of $D_K(Y_l^3)$ and are interpreted as generators of exact $N = 4$ super-conformal gauge symmetries in both quark and lepton sectors. These super-symmetries correspond to pure super gauge transformations and state the the effective 3-dimensionality of space-time dynamics.

Super-symplectic and super Kac-Moody transformations respecting the light-likeness of light-like 3-surfaces define dynamical super conformal symmetries with covariantly constant right handed neutrino spinor serving as the generator of super symmetries. These are crucial for p-adic thermodynamics. No spartners of ordinary particles are predictedin particular $N = 2$ space-time super-symmetry is generated by the righthanded neutrino is absent contrary to the earlier beliefs. There is no need to emphasize the experimental implications of this finding.

An essential difference with respect to the standard super-conformal symmetries is that Majorana condition is not satisfied and the usual super-space formalism does not apply. The notion of super-space is un-necessary since fermionic super-generators do not anticommute to vector fields of symmetries but to their Hamiltonians.

1.2.3 Identification of configuration space gamma matrices

Configuration space gamma matrices identified as super generators of super-symplectic or super Kac-Moody algebras (depending on CH coordinates used) are expressible in terms of the oscillator operators associated with the eigen modes of the modified Dirac operator. Super-symplectic and super Kac-Moody charges are expressible as integrals over 2-dimensional partonic surfaces X^2 and interior degrees of freedom of X^4 can be regarded as zero modes representing classical variables in one-one correspondence with quantal degrees of freedom at X^3_l as indeed required by quantum measurement theory. The resulting situation is highly reminiscent of WZW model and the results imply that at technical level the methods of 2-D conformal field theories should allow to construct quantum TGD.

1.3 The exponent of Kähler function as Dirac determinant for the modified Dirac action?

Although quantum criticality in principle predicts the possible values of Kähler coupling strength, one might hope that there exists even more fundamental approach involving no coupling constants and predicting even quantum criticality and realizing quantum gravitational holography.

1. The Dirac determinant defined by the product of Dirac determinants associated with the light-like partonic 3-surfaces X^3_l associated with a given space-time sheet X^4 is the simplest candidate for vacuum functional identifiable as the exponent of the Kähler function. One can of course worry about the finiteness of the Dirac determinant. p-Adicization requires that the eigenvalues belong to a given algebraic extension of rationals. This restriction would imply a hierarchy of physics corresponding to different extensions and could automatically imply the finiteness and algebraic number property of the Dirac determinants if only finite number of eigenvalues would contribute. The regularization would be performed by physics itself if this were the case.

2. The basic problem has been how to feed in the information about the preferred extremal of Kähler action to the eigenvalue spectrum of the Dirac operator in question. The identification of the preferred extremal associated with X^3_l became possible via the boundary conditions at X^3_l dictated by number theoretical compactification, which also predicted the dual slicings of the M^4 projection of space-time surface by string world sheets and partonic 2-surfaces. The basic observation is that the Dirac equation associated with the 4-D Dirac operator D_K associated with by Kähler action can be seen as a conservation law for a super current. The slicing of $X^4(X^3_l)$ by the parallel light-like 3-surfaces Y^3_l allows solutions for which the super current flows along Y^3_l and has no component in normal direction. The zero modes of D_K reducing to effectively 3-D solutions of D_K at each Y^3_l give a family of holographic copies of X^3_l. The effective 3-dimensionality is due to the super-conformal gauge invariance in the direction of light-like coordinate u labeling the 3-surfaces Y^3_l.

   A physically attractive unique realization of the slicings of space-time surface by 3-surfaces and string world sheets is discussed in [13] by starting from the observation that TGD could define a natural realization of braids, braid cobordisms, and 2-knots.

3. The spectrum of eigenvalues corresponds to the "energy" spectrum of D_K and the product of the eigenvalues defines the Dirac determinant in standard manner. If the eigenmodes are restricted to those localized to regions of strong induced electro-weak magnetic field, the number of eigen modes is finite and therefore also Dirac determinant is finite.

4. The requirement that the Noether currents associated with Dirac Kähler action are conserved is that preferred extremals of Kähler action correspond to extremals for which the second variation of Kähler action vanishes at least for the deformations associated with the conserved currents. Obviously this is nothing but the formulation of quantum criticality at space-time level!

5. The physical analog is energy spectrum for Dirac operator in external magnetic field. The effective metric appearing in the modified Dirac operator corresponds to $\hat{g}^{\alpha\beta} = \partial L_K/\partial h^k_\alpha \partial L_K/\partial h^l_\beta h_{kl}$, and vanishes at the boundaries of regions carrying non-vanishing Kähler magnetic field. Hence the modes must be localized to regions $X^3_{l,i}$ containing a non-vanishing Kähler magnetic field. Cyclotron states in constant magnetic field serve as a good analog for the situation and only a finite number of cyclotron states are possible since for higher cyclotron states the wave function -essentially harmonic oscillator wave function- would concentrate outside $X^3_{l,i}$.

6. A more precise argument goes as follows. Assume that it is induced Kähler magnetic field B_K that matters. The vanishing of the effective contravariant metric near the boundary of $X^3_{l,i}$ corresponds to an infinite effective mass for massive particle in constant magnetic field so that the counterpart for the cyclotron frequency scale eB/m reduces to zero. The radius of the cyclotron orbit is proportional to $1/\sqrt{eB}$ and approaches to infinity. Hence the required localization is not possible only for cyclotron states for which the cyclotron radius is below that the transversal size scale of $X^3_{l,i}$.

7. It remains to be proven that the product of eigenvalues gives rise to the exponent of Kähler action for the preferred extremal of Kähler action. At this moment the only justification for the conjecture is that this the only thing that one can imagine.

1.4 Super-conformal symmetries

The almost topological QFT property of partonic formulation based on modified Dirac Kähler action allows a rich structure of $N = 4$ super-conformal symmetries. In particular, the generalized Kac-Moody symmetries leave corresponding X^3-local isometries respecting the light-likeness condition. A rather detailed view about various aspects of super-conformal symmetries emerge leading to identification of fermionic anti-commutation relations and explicit expressions for configuration space gamma matrices and Kähler metric. This picture is consistent with the conditions posed by p-adic mass calculations.

The relationship between super-symplectic (SC) and Super Kac-Moody (SKM) symmetries has been one of the central themes in the development of TGD. The progress in the understanding of the number theoretical aspects of TGD gives good hopes of lifting $SKMV$ (V denotes Virasoro) to a subalgebra of SCV so that coset construction works meaning that the differences of SCV and $SKMV$ generators annihilate physical states. This condition has interpretation in terms of Equivalence Principle with coset Super Virasoro conditions defining a generalization of Einstein's equations in TGD framework. Also p-adic thermodynamics finds a justification since the expectation values of SKM conformal weights can be non-vanishing in physical states.

Number theoretical considerations play a key role and lead to the picture in which effective discretization occurs so that partonic two-surface is effectively replaced by a discrete set of algebraic points belonging to the intersection of the real partonic 2-surface and its p-adic counterpart obeying the same algebraic equations. This implies effective discretization of super-conformal field theory giving N-point functions defining vertices via discrete versions of stringy formulas.

Before continuing I must represent apologies for the reader. This chapter is just now under updating due to the dramatic simplifications related to identification of the eigenvalue spectrum of the modified Dirac operator and the definition of the Dirac determinant. The new vision is briefly discussed but a lot of mammoth bones remains to be eliminated.

2 Configuration space spinor structure: general definition

The basic problem in constructing configuration space spinor structure is clearly the construction of the explicit representation for the gamma matrices of the configuration space. One should be able to identify the space, where these gamma matrices act as well as the counterparts of the "free" gamma matrices, in terms of which the gamma matrices would be representable using generalized vielbein coefficients.

2.1 Defining relations for gamma matrices

The ordinary definition of the gamma matrix algebra is in terms of the anti-commutators

$$\{\gamma_A, \gamma_B\} = 2g_{AB} \quad .$$

This definition served implicitly also as a basic definition of the gamma matrix algebra in TGD context until the difficulties related to the understanding of the configuration space d'Alembertian defined in terms of the square of the Dirac operator forced to reconsider the definition. If configuration space allows Kähler structure, the most general definition allows to replace the metric any covariantly constant Hermitian form. In particular, g_{AB} can be replaced with

$$\{\Gamma_A^\dagger, \Gamma_B\} = iJ_{AB} \quad , \tag{2.1}$$

where J_{AB} denotes the matrix element of the Kähler form of the configuration space. The reason is that gamma matrices carry fermion number and are non-hermitian in all coordinate systems. This definition is numerically equivalent with the standard one in the complex coordinates but in arbitrary coordinates situation is different since in general coordinates iJ_{kl} is a nontrivial positive square root of g_{kl}. The realization of this delicacy is necessary in order to understand how the square of the configuration space Dirac operator comes out correctly. Obviously, what one must do is the equivalent of replacing $D^2 = (\Gamma^k D_k)^2$ with $D\hat{D}$ with $\hat{D}$ defined as

$$\hat{D} = iJ^{kl}\Gamma_l^\dagger D_k \quad .$$

2.2 General vielbein representations

There are two ideas, which make the solution of the problem obvious.

1. Since the classical time development in bosonic degrees of freedom (induced gauge fields) is coded into the geometry of the configuration space it seems natural to expect that same applies in the case of the spinor structure. The time development of the induced spinor fields dictated by TGD counterpart of the massless Dirac action should be coded into the definition of the configuration space spinor structure. This leads to the challenge of defining what classical spinor field means.

2. Since classical scalar field in the configuration space corresponds to second quantized boson fields of the imbedding space same correspondence should apply in the case of the fermions, too. The spinor fields of configuration space should correspond to second quantized fermion field of the imbedding space and the space of the configuration space spinors should be more or less identical with the Fock space of the second quantized fermion field of imbedding space or $X^4(X^3)$. Since classical spinor fields at space-time surface are obtained by restricting the spinor structure to the space-time surface, one might consider the possibility that life is really simple: the second quantized spinor field corresponds to the free spinor field of the imbedding space satisfying the counterpart of the massless Dirac equation and more or less standard anti-commutation relations. Unfortunately life is not *so* simple as the construction of configuration space spinor structure demonstrates: second quantization must be performed for induced spinor fields.

It is relatively simple to fill in the details once these basic ideas are accepted.

1. The only natural candidate for the second quantized spinor field is just the on X^4. Since this field is free field, one can indeed perform second quantization and construct fermionic oscillator operator algebra with unique anti-commutation relations. The space of the configuration space spinors can be identified as the associated with these oscillator operators. This space depends on 3-surface and strictly speaking one should speak of the Fock bundle having configuration space as its base space.

2. The gamma matrices of the configuration space (or rather fermionic Kac Moody generators) are representable as super positions of the fermionic oscillator algebra generators:

$$
\begin{aligned}
\Gamma_A^+ &= E_A^n a_n^\dagger \\
\Gamma_A^- &= \bar{E}_A^n a_n \\
iJ_{A\bar{B}} &= \sum_n E_A^n \bar{E}_B^n
\end{aligned}
\tag{2.2}
$$

where E_A^n are the vielbein coefficients. Induced spinor fields can possess zero modes and there is no oscillator operators associated with these modes. Since oscillator operators are spin 1/2 objects, configuration space gamma matrices are analogous to spin 3/2 spinor fields (in a very general sense). Therefore the generalized vielbein and configuration space metric is analogous to the pair of spin 3/2 and spin 2 fields encountered in super gravitation! Notice that the contractions $j^{Ak}\Gamma_k$ of the complexified gamma matrices with the isometry generators are genuine spin 1/2 objects labeled by the quantum numbers labeling isometry generators. In particular, in CP_2 degrees of freedom these fermions are color octets.

3. A further great idea inspired by the symplectic and Kähler structures of the configuration space is that configuration gamma matrices are actually generators of super-symplectic symmetries. This simplifies enormously the construction allows to deduce explicit formulas for the gamma matrices.

2.3 Inner product for configuration space spinor fields

The conjugation operation for configuration space spinors corresponds to the standard $ket \rightarrow bra$ operation for the states of the Fock space:

$$
\begin{aligned}
\Psi &\leftrightarrow |\Psi\rangle \\
\bar{\Psi} &\leftrightarrow \langle\Psi|
\end{aligned}
\tag{2.3}
$$

The inner product for configuration space spinors at a given point of the configuration space is just the standard Fock space inner product, which is unitary.

$$
\bar{\Psi}_1(X^3)\Psi_2(X^3) = \langle\Psi_1|\Psi_2\rangle_{|X^3} \tag{2.4}
$$

Configuration space inner product for two configuration space spinor fields is obtained as the integral of the Fock space inner product over the whole configuration space using the vacuum functional $exp(K)$ as a weight factor

$$
\langle\Psi_1|\Psi_2\rangle = \int \langle\Psi_1|\Psi_2\rangle_{|X^3} exp(K)\sqrt{G}dX^3 \tag{2.5}
$$

This inner product is obviously unitary. A modified form of the inner product is obtained by including the factor $exp(K/2)$ in the definition of the spinor field. In fact, the construction of the central extension for the isometry algebra leads automatically to the appearance of this factor in vacuum spinor field.

The inner product differs from the standard inner product for, say, Minkowski space spinors in that integration is over the entire configuration space rather than over a time= constant slice of the configuration space. Also the presence of the vacuum functional makes it different from the finite dimensional inner product. These are not un-physical features. The point is that (apart from classical non-determinism forcing to generalized the concept of 3-surface) Diff^4 invariance dictates the behavior of the configuration space spinor field completely: it is determined form its values at the moment of the big bang. Therefore there is no need to postulate any Dirac equation to determine the behavior and therefore no need to use the inner product derived from dynamics.

2.4 Holonomy group of the vielbein connection

Generalized vielbein allows huge gauge symmetry. An important constraint on physical observables is that they do not depend at all on the gauge chosen to represent the gamma matrices. This is indeed achieved using vielbein connection, which is now quadratic in fermionic oscillator operators. The holonomy group of the vielbein connection is the configuration space counterpart of the electro-weak gauge group and its algebra is expected to have same general structure as the algebra of the configuration space isometries. In particular, the generators of this algebra should be labeled by conformal weights like the elements of Kac Moody algebras. In present case however conformal weights are complex as the construction of the configuration space geometry demonstrates.

2.5 Realization of configuration space gamma matrices in terms of super symmetry generators

In string models super symmetry generators behave effectively as gamma matrices and it is very tempting to assume that configuration space gamma matrices can be regarded as generators of the symplectic algebra extended to super-symplectic Kac Moody type algebra. The experience with string models suggests also that radial Virasoro algebra extends to Super Virasoro algebra. There are good reasons to expect that configuration space Dirac operator and its square give automatically a realization of this algebra. It this is indeed the case, then configuration space spinor structure as well as Dirac equation reduces to mere group theory.

One can actually guess the general form of the super-symplectic algebra. The form is a direct generalization of the ordinary super Kac Moody algebra. The complexified super generators S_A are identifiable as configuration space gamma matrices:

$$\Gamma_A = S_A \ . \tag{2.6}$$

The anti-commutators $\{\Gamma^\dagger_A, \Gamma_B\}_+ = i2J_{A,B}$ define a Hermitian matrix, which is proportional to the Kähler form of the configuration space rather than metric as usually. Only in complex coordinates the anti-commutators equal to the metric numerically. This is, apart from the multiplicative constant n, is expressible as the Poisson bracket of the configuration space Hamiltonians H_A and H_B. Therefore one should be able to identify super generators $S_A(r_M)$ for each values of r_M as the counterparts of fluxes. The anti-commutators between the super generators S_A and their Hermitian conjugates should read as

$$\{S_A, S^\dagger_B\}_+ = iQ_m(H_{[A,B]}) \ . \tag{2.7}$$

and should be induced directly from the anti-commutation relations of free second quantized spinor fields of the imbedding space restricted to the light cone boundary.

The commutation relations between s and super generators follow solely from the transformation properties of the super generators under symplectic transformations, which are same as for the Hamiltonians themselves

$$\{H_{Am}, S_{Bn}\}_- = S_{[Am,Bn]} \ , \tag{2.8}$$

and are of the same form as in the case of Super-Kac-Moody algebra.

The task is to derive an explicit representation for the super generators S_A in both cases. For obvious reason the spinor fields restricted to the 3-surfaces on the light cone boundary $\delta M^4_+ \times CP_2$ can be used. Leptonic/quark like oscillator operators are used to construct Ramond/NS type algebra.

What is then the strategy that one should follow?

1. Configuration space Hamiltonians correspond to either magnetic or electric flux Hamiltonians and the conjecture is that these representations are equivalent. It turns out that this electric-magnetic duality generalizes to the level of super charges. It also turns out that quark representation is the only possible option whereas leptonic super charges super-symmetrize the ordinary function algebra of the light cone boundary.

2. The simplest option would be that second quantized imbedding space spinors could be used in the definition of super charges. This turns out to not work and one must second quantize the induced spinor fields.

3. The task is to identify a super-symmetric variational principle for the induced spinors: ordinary Dirac action does not work. It turns out that in the most plausible scenario the modified Dirac action varied with respect to *both* imbedding space coordinates and spinor fields is the fundamental action principle. The c-number parts of the conserved symplectic charges associated with this action give rise to bosonic conserved charges defining configuration space Hamiltonians. The second quantization of the spinor fields reduces to the requirement that super charges and Hamiltonians generate super-symplectic algebra determining the anti-commutation relations for the induced spinor fields.

2.6 Central extension as symplectic extension at configuration space level

The earlier attempts to understand the emergence of central extension of super-symplectic algebra were based on the notion of symplectic extension. This general view is not given up although it seems that this abstract approach is not very practical. Symplectic extension emerged originally in the attempts to construct formal expression for the configuration space Dirac equation. The rather obvious idea was that the Dirac equation reduces to super Virasoro conditions with Super Virasoro generators involving the Dirac operator of the imbedding space. The basic difficulty was the necessity to assign to the gamma matrices of the imbedding space fermion number. In the recent formulation the Dirac operator of H does not appear in in the Super Virasoro conditions so that this problem disappears.

The proposal that Super Virasoro conditions should replaced with conditions stating that the commutator of super-symplectic and super Kac-Moody algebras annihilates physical states, looks rather feasible. One could call these conditions as configuration space Dirac equation but at this moment I feel that this would be just play with words and mask the group theoretical content of these conditions. In any case, the formulas for the symplectic extension and action of isometry generators on configuration space spinor deserve to be summarized.

2.6.1 Symplectic extension

The Abelian extension of the super-symplectic algebra is obtained by an extremely simple trick. Replace the ordinary derivatives appearing in the definition of, say spinorial isometry generator, by the covariant derivatives defined by a coupling to a multiple of the Kähler potential.

$$\begin{aligned} j^{Ak}\partial_k &\rightarrow j^{Ak}D_k \ , \\ D_k &= \partial_k + ikA_k/2 \ . \end{aligned} \tag{2.9}$$

where A_k denotes Kähler potential. The reality of the parameter k is dictated by the Hermiticity requirement and also by the requirement that Abelian extension reduces to the standard form in Cartan algebra. k is expected to be integer also by the requirement that covariant derivative corresponds to connection (quantization of magnetic charge).

The commutation relations for the centrally extended generators J^A read:

$$[J^A, J^B] = J^{[A,B]} + ikj^{Ak}J_{kl}j^{Bl} \equiv J^{[A,B]} + ikJ_{AB} \ . \tag{2.10}$$

Since Kähler form defines symplectic structure in configuration space one can express Abelian extension term as a Poisson bracket of two Hamiltonians

$$J_{AB} \equiv j^{Ak}J_{kl}j^{Bl} = \{H^A, H^B\} \ . \tag{2.11}$$

Notice that Poisson bracket is well defined also when Kähler form is degenerate.

The extension indeed has acceptable properties:

1. Jacobi-identities reduce to the form

$$\sum_{cyclic} H^{[A,[B,C]]} = 0 \ , \tag{2.12}$$

and therefore to the Jacobi identities of the original Lie- algebra in Hamiltonian representation.

2. In the Cartan algebra Abelian extension reduces to a constant term since the Poisson bracket for two commuting generators must be a multiple of a unit matrix. This feature is clearly crucial for the non-triviality of the Abelian extension and is encountered already at the level of ordinary (q,p) Poisson algebra: although the differential operators ∂_p and ∂_q commute the Poisson bracket of the corresponding Hamiltonians p and q is nontrivial: $\{p,q\} = 1$. Therefore the extension term commutes with the generators of the Cartan subalgebra. Extension is also local $U(1)$ extension since Poisson algebra differs from the Lie-algebra of the vector fields in that it contains constant Hamiltonian ("1" in the commutator), which commutes with all other Hamiltonians and corresponds to a vanishing vector field.

3. For the generators not belonging to Cartan sub-algebra of CH isometries Abelian extension term is not annihilated by the generators of the original algebra and in this respect the extension differs from the standard central extension for the loop algebras. It must be however emphasized that for the super-symplectic algebra generators correspond to products of δM^4_+ and CP_2 Hamiltonians and this means that generators of say δM^4_+-local $SU(3)$ Cartan algebra are non-commuting and the commutator is completely analogous to central extension term since it is symmetric with respect to $SU(3)$ generators.

4. The proposed method yields a trivial extension in the case of Diff^4. The reason is the (four-dimensional!) Diff degeneracy of the Kähler form. Abelian extension term is given by the contraction of the Diff^4 generators with the Kähler potential

$$j^{Ak} J_{kl} j^{Bl} = 0 \ , \tag{2.13}$$

which vanishes identically by the Diff degeneracy of the Kähler form. Therefore neither 3- or 4-dimensional Diff invariance is not expected to cause any difficulties. Recall that 4-dimensional Diff degeneracy is what is needed to eliminate time like vibrational excitations from the spectrum of the theory. By the way, the fact that the loop space metric is not Diff degenerate makes understandable the emergence of Diff anomalies in string models [5, 2] .

5. The extension is trivial also for the other zero norm generators of the tangent space algebra, in particular for the $k_2 = Im(k) = 0$ symplectic generators possible present so that these generators indeed act as genuine $U(1)$ transformations.

6. Concerning the solution of configuration space Dirac equation the maximum of Kähler function is expected to be special, much like origin of Minkowski space and symmetric space property suggests that the construction of solutions reduces to this point. At this point the generators and Hamiltonians of the algebra h in the defining Cartan decomposition $g = h + t$ should vanish. h corresponds to integer values of $k_1 = Re(k)$ for Cartan algebra of super-symplectic algebra and integer valued conformal weights n for Super Kac-Moody algebra. The algebra reduces at the maximum to an exceptionally simple form since only central extension contributes to the metric and Kähler form. In the ideal case the elements of the metric and Kähler form could be even diagonal. The degeneracy of the metric might of course pose additional complications.

2.6.2 Super symplectic action on configuration space spinors

The generators of symplectic transformations are obtained in the spinor representation of the isometry group of the configuration space by the following formal construction. Take isometry generator in the spinor representation and add to the covariant derivative D_k defined by vielbein connection the coupling to the multiple of the Kähler potential: $D_k \rightarrow D_k + ikAk/2$.

$$
\begin{aligned}
J^A &= j^{Ak}D_k + D_l j_k \Sigma^{kl}/2 \ , \\
&\rightarrow \ \hat{J}^A = j^{Ak}(D_k + ikA_k/2) + D_l j^A_k \Sigma^{kl}/2 \ ,
\end{aligned}
\tag{2.14}
$$

This induces the required central term to the commutation relations. Introduce complex coordinates and define bosonic creation and annihilation operators as $(1,0)$ and $(0,1)$ parts of the modified isometry generators

$$
\begin{aligned}
B^\dagger_A &= J^A_+ = j^{Ak}(D_k + ... \ , \\
B_A &= J^A_- = j^{A\bar{k}}(D_{\bar{k}} + ... \ .
\end{aligned}
\tag{2.15}
$$

where "k" refers now to complex coordinates and "$\bar{k}$" to their conjugates.

Fermionic generators are obtained as the contractions of the complexified gamma matrices with the isometry generators

$$
\begin{aligned}
\Gamma^\dagger_A &= j^{Ak}\Gamma_k \ , \\
\Gamma_A &= j^{A\bar{k}}\Gamma_{\bar{k}} \ .
\end{aligned}
\tag{2.16}
$$

Notice that the bosonic Cartan algebra generators obey standard oscillator algebra commutation relations and annihilate fermionic Cartan algebra generators. Hermiticity condition holds in the sense that creation type generators are hermitian conjugates of the annihilation operator type generators. There are two kinds of representations depending on whether one uses leptonic or quark like oscillator operators to construct the gammas. These will be assumed to correspond to Ramond and NS type generators with the radial plane waves being labeled by integer and half odd integer indices respectively.

The non-vanishing commutators between the Cartan algebra bosonic generators are given by the matrix elements of the Kähler form in the basis of formed by the isometry generators

$$
[B^\dagger_A, B_B] = J(j^{A\dagger}, j^B) \equiv J_{\bar{A}B} \ . \tag{2.17}
$$

and are isometry invariant quantities. The commutators between local $SU(3)$ generators not belonging to Cartan algebra are just those of the local gauge algebra with Abelian extension term added.

The anti-commutators between the fermionic generators are given by the elements of the metric (as opposed to Kähler form in the case of bosonic generators) in the basis formed by the isometry generators

$$
\{\Gamma_A\dagger, \Gamma_B\} = 2g(j^{A\dagger}, j^B) \equiv 2g_{\bar{A}B} \ . \tag{2.18}
$$

and are invariant under isometries. Numerically the commutators and anti-commutators differ only the presence of the imaginary unit and the scale factor R relating the metric and Kähler form to each other (the factor R is same for CP_2 metric and Kähler form).

The commutators between bosonic and fermionic generators are given by

$$
[B_A, \Gamma_B] = \Gamma_{[A,B]} \ . \tag{2.19}
$$

The presence of vielbein and rotation terms in the representation of the isometry generators is essential for obtaining these nice commutations relations. The commutators vanish identically for Cartan algebra generators. From the commutation relations it is clear that Super Kac Moody algebra structure is directly related to the Kähler structure of the configuration space: the anti-commutator of fermionic generators is proportional to the metric and the commutator of the bosonic generators is proportional to the Kähler form. It is this algebra, which should generate the solutions of the field equations of the theory.

The vielbein and rotational parts of the bosonic isometry generators are quadratic in the fermionic oscillator operators and this suggests the interpretation as the fermionic contribution to the isometry currents. This means that the action of the bosonic generators is essentially non-perturbative since it creates fermion antifermion pairs besides exciting bosonic degrees of freedom.

2.7 Configuration space Clifford algebra as a hyper-finite factor of type II_1

The naive expectation is that the trace of the unit matrix associated with the Clifford algebra spanned by configuration space sigma matrices is infinite and thus defines an excellent candidate for a source of divergences in perturbation theory. This potential source of infinities remained un-noticed until it became clear that there is a connection with von Neumann algebras [12] . In fact, for a separable Hilbert space defines a standard representation for so called [13] . This guarantees that the trace of the unit matrix equals to unity and there is no danger about divergences.

2.7.1 Philosophical ideas behind von Neumann algebras

The goal of von Neumann was to generalize the algebra of quantum mechanical observables. The basic ideas behind the von Neumann algebra are dictated by physics. The algebra elements allow Hermitian conjugation * and observables correspond to Hermitian operators. Any measurable function $f(A)$ of operator A belongs to the algebra and one can say that non-commutative measure theory is in question.

The predictions of quantum theory are expressible in terms of traces of observables. Density matrix defining expectations of observables in ensemble is the basic example. The highly non-trivial requirement of von Neumann was that identical a priori probabilities for a detection of states of infinite state system must make sense. Since quantum mechanical expectation values are expressible in terms of operator traces, this requires that unit operator has unit trace: $tr(Id) = 1$.

In the finite-dimensional case it is easy to build observables out of minimal projections to 1-dimensional eigen spaces of observables. For infinite-dimensional case the probably of projection to 1-dimensional sub-space vanishes if each state is equally probable. The notion of observable must thus be modified by excluding 1-dimensional minimal projections, and allow only projections for which the trace would be infinite using the straightforward generalization of the matrix algebra trace as the dimension of the projection.

The non-trivial implication of the fact that traces of projections are never larger than one is that the eigen spaces of the density matrix must be infinite-dimensional for non-vanishing projection probabilities. Quantum measurements can lead with a finite probability only to mixed states with a density matrix which is projection operator to infinite-dimensional subspace. The simple von Neumann algebras for which unit operator has unit trace are known as factors of type II_1 [13] .

The definitions of adopted by von Neumann allow however more general algebras. Type I_n algebras correspond to finite-dimensional matrix algebras with finite traces whereas I_∞ associated with a separable infinite-dimensional Hilbert space does not allow bounded traces. For algebras of type III non-trivial traces are always infinite and the notion of trace becomes useless.

2.7.2 von Neumann, Dirac, and Feynman

The association of algebras of type I with the standard quantum mechanics allowed to unify matrix mechanism with wave mechanics. Note however that the assumption about continuous momentum state basis is in conflict with separability but the particle-in-box idealization allows to circumvent this problem (the notion of space-time sheet brings the box in physics as something completely real).

Because of the finiteness of traces von Neumann regarded the factors of type II_1 as fundamental and factors of type III as pathological. The highly pragmatic and successful approach of Dirac based on the notion of delta function, plus the emergence of Feynman graphs, the possibility to formulate the notion of delta function rigorously in terms of distributions, and the emergence of path integral approach meant that von Neumann approach was forgotten by particle physicists.

Algebras of type II_1 have emerged only much later in conformal and topological quantum field theories [15, 17] allowing to deduce invariants of knots, links and 3-manifolds. Also algebraic structures known as bi-algebras, Hopf algebras, and ribbon algebras [14, 10] relate closely to type II_1 factors. In topological quantum computation [4] based on braid groups [11] modular S-matrices they play an especially important role.

2.7.3 Clifford algebra of configuration space as von Neumann algebra

The Clifford algebra of the configuration space provides a school example of a hyper-finite factor of type II_1, which means that fermionic sector does not produce divergence problems. Super-symmetry means that also "orbital" degrees of freedom corresponding to the deformations of 3-surface define similar factor. The general theory of hyper-finite factors of type II_1 is very rich and leads to rather detailed understanding of the general structure of S-matrix in TGD framework. For instance, there is a unitary evolution operator intrinsic to the von Neumann algebra defining in a natural manner single particle time evolution. Also a connection with 3-dimensional topological quantum field theories and knot theory, conformal field theories, braid groups, quantum groups, and quantum counterparts of quaternionic and octonionic division algebras emerges naturally. These aspects are discussed in detail in [30] .

3 Hierarchy of Planck constants and the generalization of the notion of imbedding space

In the following the recent view about structure of imbedding space forced by the quantization of Planck constant is summarized. The question is whether it might be possible in some sense to replace H or its Cartesian factors by their necessarily singular multiple coverings and factor spaces. One can consider two options: either M^4 or the causal diamond CD. The latter one is the more plausible option from the point of view of WCW geometry.

3.1 The evolution of physical ideas about hierarchy of Planck constants

The evolution of the physical ideas related to the hierarchy of Planck constants and dark matter as a hierarchy of phases of matter with non-standard value of Planck constants was much faster than the evolution of mathematical ideas and quite a number of applications have been developed during last five years.

1. The starting point was the proposal of Nottale [1] that the orbits of inner planets correspond to Bohr orbits with Planck constant $\hbar_{gr} = GMm/v_0$ and outer planets with Planck constant $\hbar_{gr} = 5GMm/v_0$, $v_0/c \simeq 2^{-11}$. The basic proposal [23, 21] was that ordinary matter condenses around dark matter which is a phase of matter characterized by a non-standard value of Planck constant whose value is gigantic for the space-time sheets mediating gravitational interaction. The interpretation of these space-time sheets could be as magnetic flux quanta or as massless extremals assignable to gravitons.

2. Ordinary particles possibly residing at these space-time sheet have enormous value of Compton length meaning that the density of matter at these space-time sheets must be very slowly varying. The string tension of string like objects implies effective negative pressure characterizing dark energy so that the interpretation in terms of dark energy might make sense [24] . TGD predicted a one-parameter family of Robertson-Walker cosmologies with critical or over-critical mass density and the "pressure" associated with these cosmologies is negative.

3. The quantization of Planck constant does not make sense unless one modifies the view about standard space-time is. Particles with different Planck constant must belong to different worlds in the sense local interactions of particles with different values of $\hbar$ are not possible. This inspires the idea about the book like structure of the imbedding space obtained by gluing almost copies of H together along common "back" and partially labeled by different values of Planck constant.

4. Darkness is a relative notion in this framework and due to the fact that particles at different pages of the book like structure cannot appear in the same vertex of the generalized Feynman diagram. The phase transitions in which partonic 2-surface X^2 during its travel along X^3_l leaks to another page of book are however possible and change Planck constant. Particle (say photon

-) exchanges of this kind allow particles at different pages to interact. The interactions are strongly constrained by charge fractionization and are essentially phase transitions involving many particles. Classical interactions are also possible. It might be that we are actually observing dark matter via classical fields all the time and perhaps have even photographed it [28] .

5. The realization that non-standard values of Planck constant give rise to charge and spin fractionization and anyonization led to the precise identification of the prerequisites of anyonic phase. If the partonic 2-surface, which can have even astrophysical size, surrounds the tip of CD, the matter at the surface is anyonic and particles are confined at this surface. Dark matter could be confined inside this kind of light-like 3-surfaces around which ordinary matter condenses. If the radii of the basic pieces of these nearly spherical anyonic surfaces - glued to a connected structure by flux tubes mediating gravitational interaction - are given by Bohr rules, the findings of Nottale [1] can be understood. Dark matter would resemble to a high degree matter in black holes replaced in TGD framework by light-like partonic 2-surfaces with a minimum size of order Schwartschild radius r_S of order scaled up Planck length $l_{Pl} = \sqrt{\hbar_{gr} G} = GM$. Black hole entropy is inversely proportional to $\hbar$ and predicted to be of order unity so that dramatic modification of the picture about black holes is implied.

6. Perhaps the most fascinating applications are in biology. The anomalous behavior ionic currents through cell membrane (low dissipation, quantal character, no change when the membrane is replaced with artificial one) has a natural explanation in terms of dark supra currents. This leads to a vision about how dark matter and phase transitions changing the value of Planck constant could relate to the basic functions of cell, functioning of DNA and aminoacids, and to the mysteries of bio-catalysis. This leads also a model for EEG interpreted as a communication and control tool of magnetic body containing dark matter and using biological body as motor instrument and sensory receptor. One especially amazing outcome is the emergence of genetic code of vertebrates from the model of dark nuclei as nuclear strings [1, 28] , [1] .

3.2 The most general option for the generalized imbedding space

Simple physical arguments pose constraints on the choice of the most general form of the imbedding space.

1. The fundamental group of the space for which one constructs a non-singular covering space or factor space should be non-trivial. This is certainly not possible for M^4, CD, CP_2, or H. One can however construct singular covering spaces. The fixing of the quantization axes implies a selection of the sub-space $H_4 = M^2 \times S^2 \subset M^4 \times CP_2$, where S^2 is geodesic sphere of CP_2. $\hat{M}^4 = M^4 \backslash M^2$ and $\hat{CP}_2 = CP_2 \backslash S^2$ have fundamental group Z since the codimension of the excluded sub-manifold is equal to two and homotopically the situation is like that for a punctured plane. The exclusion of these sub-manifolds defined by the choice of quantization axes could naturally give rise to the desired situation.

2. CP_2 allows two geodesic spheres which left invariant by $U(2$ *resp.* $SO(3)$. The first one is homologically non-trivial. For homologically non-trivial geodesic sphere $H_4 = M^2 \times S^2$ represents a straight cosmic string which is non-vacuum extremal of Kähler action (not necessarily preferred extremal). One can argue that the many-valuedness of $\hbar$ is un-acceptable for non-vacuum extremals so that only homologically trivial geodesic sphere S^2 would be acceptable. One could go even further. If the extremals in $M^2 \times CP_2$ can be preferred non-vacuum extremals, the singular coverings of M^4 are not possible. Therefore only the singular coverings and factor spaces of CP_2 over the homologically trivial geodesic sphere S^2 would be possible. This however looks a non-physical outcome.

   (a) The situation changes if the extremals of type $M^2 \times Y^2$, Y^2 a holomorphic surface of CP_3, fail to be hyperquaternionic. The tangent space M^2 represents hypercomplex sub-space and the product of the modified gamma matrices associated with the tangent spaces of Y^2 should belong to M^2 algebra. This need not be the case in general.

(b) The situation changes also if one reinterprets the gluing procedure by introducing scaled up coordinates for M^4 so that metric is continuous at $M^2 \times CP_2$ but CDs with different size have different sizes differing by the ratio of Planck constants and would thus have only piece of lower or upper boundary in common.

3. For the more general option one would have four different options corresponding to the Cartesian products of singular coverings and factor spaces. These options can be denoted by $C-C$, $C-F$, $F-C$, and $F-F$, where C (F) signifies for covering (factor space) and first (second) letter signifies for CD (CP_2) and correspond to the spaces $(\hat{CD}\hat{\times}G_a) \times (\hat{CP_2}\hat{\times}G_b)$, $(\hat{CD}\hat{\times}G_a) \times \hat{CP_2}/G_b$, $\hat{CD}/G_a \times (\hat{CP_2}\hat{\times}G_b)$, and $\hat{CD}/G_a \times \hat{CP_2}/G_b$.

4. The groups G_i could correspond to cyclic groups Z_n. One can also consider an extension by replacing M^2 and S^2 with its orbit under more general group G (say tedrahedral, octahedral, or icosahedral group). One expects that the discrete subgroups of $SU(2)$ emerge naturally in this framework if one allows the action of these groups on the singular sub-manifolds M^2 or S^2. This would replace the singular manifold with a set of its rotated copies in the case that the subgroups have genuinely 3-dimensional action (the subgroups which corresponds to exceptional groups in the ADE correspondence). For instance, in the case of M^2 the quantization axes for angular momentum would be replaced by the set of quantization axes going through the vertices of tedrahedron, octahedron, or icosahedron. This would bring non-commutative homotopy groups into the picture in a natural manner.

3.3 About the phase transitions changing Planck constant

There are several non-trivial questions related to the details of the gluing procedure and phase transition as motion of partonic 2-surface from one sector of the imbedding space to another one.

1. How the gluing of copies of imbedding space at $M^2 \times CP_2$ takes place? It would seem that the covariant metric of CD factor proportional to $\hbar^2$ must be discontinuous at the singular manifold since only in this manner the idea about different scaling factor of CD metric can make sense. On the other hand, one can always scale the M^4 coordinates so that the metric is continuous but the sizes of CDs with different Planck constants differ by the ratio of the Planck constants.

2. One might worry whether the phase transition changing Planck constant means an instantaneous change of the size of partonic 2-surface in M^4 degrees of freedom. This is not the case. Light-likeness in $M^2 \times S^2$ makes sense only for surfaces $X^1 \times D^2 \subset M^2 \times S^2$, where X^1 is light-like geodesic. The requirement that the partonic 2-surface X^2 moving from one sector of H to another one is light-like at $M^2 \times S^2$ irrespective of the value of Planck constant requires that X^2 has single point of M^2 as M^2 projection. Hence no sudden change of the size X^2 occurs.

3. A natural question is whether the phase transition changing the value of Planck constant can occur purely classically or whether it is analogous to quantum tunneling. Classical non-vacuum extremals of Chern-Simons action have two-dimensional CP_2 projection to homologically non-trivial geodesic sphere S^2_I. The deformation of the entire S^2_I to homologically trivial geodesic sphere S^2_{II} is not possible so that only combinations of partonic 2-surfaces with vanishing total homology charge (Kähler magnetic charge) can in principle move from sector to another one, and this process involves fusion of these 2-surfaces such that CP_2 projection becomes single homologically trivial 2-surface. A piece of a non-trivial geodesic sphere S^2_I of CP_2 can be deformed to that of S^2_{II} using 2-dimensional homotopy flattening the piece of S^2 to curve. If this homotopy cannot be chosen to be light-like, the phase transitions changing Planck constant take place only via quantum tunnelling. Obviously the notions of light-like homotopies (cobordisms) are very relevant for the understanding of phase transitions changing Planck constant.

3.4 How one could fix the spectrum of Planck constants?

The question how the observed Planck constant relates to the integers n_a and n_b defining the covering and factors spaces, is far from trivial and I have considered several options. The basic physical inputs are the condition that scaling of Planck constant must correspond to the scaling of the metric of CD

(that is Compton lengths) on one hand and the scaling of the gauge coupling strength $g^2/4\pi\hbar$ on the other hand.

1. One can assign to Planck constant to both CD and CP_2 by assuming that it appears in the commutation relations of corresponding symmetry algebras. Algebraist would argue that Planck constants $\hbar(CD)$ and $\hbar(CP_2)$ must define a homomorphism respecting multiplication and division (when possible) by G_i. This requires $r(X) = \hbar(X)\hbar_0 = n$ for covering and $r(X) = 1/n$ for factor space or vice versa.

2. If one assumes that $\hbar^2(X)$, $X = M^4$, CP_2 corresponds to the scaling of the covariant metric tensor g_{ij} and performs an over-all scaling of H-metric allowed by the Weyl invariance of Kähler action by dividing metric with $\hbar^2(CP_2)$, one obtains the scaling of M^4 covariant metric by $r^2 \equiv \hbar^2/\hbar_0^2 = \hbar^2(M^4)/\hbar^2(CP_2)$ whereas CP_2 metric is not scaled at all.

3. The condition that $\hbar$ scales as n_a is guaranteed if one has $\hbar(CD) = n_a\hbar_0$. This does not fix the dependence of $\hbar(CP_2)$ on n_b and one could have $\hbar(CP_2) = n_b\hbar_0$ or $\hbar(CP_2) = \hbar_0/n_b$. The intuitive picture is that n_b- fold covering gives in good approximation rise to $n_a n_b$ sheets and multiplies YM action action by $n_a n_b$ which is equivalent with the $\hbar = n_a n_b \hbar_0$ if one effectively compresses the covering to $CD \times CP_2$. One would have $\hbar(CP_2) = \hbar_0/n_b$ and $\hbar = n_a n_b \hbar_0$. Note that the descriptions using ordinary Planck constant and coverings and scaled Planck constant but contracting the covering would be alternative descriptions.

   This gives the following formulas $r \equiv \hbar/\hbar_0 = r(M^4)/r(CP_2)$ in various cases.

	$C-C$	$F-C$	$C-F$	$F-F$
r	$n_a n_b$	$\frac{n_a}{n_b}$	$\frac{n_b}{n_a}$	$\frac{1}{n_a n_b}$

3.5 Preferred values of Planck constants

Number theoretic considerations favor the hypothesis that the integers corresponding to Fermat polygons constructible using only ruler and compass and given as products $n_F = 2^k \prod_s F_s$, where $F_s = 2^{2^s} + 1$ are distinct Fermat primes, are favored. The reason would be that quantum phase $q = exp(i\pi/n)$ is in this case expressible using only iterated square root operation by starting from rationals. The known Fermat primes correspond to $s = 0, 1, 2, 3, 4$ so that the hypothesis is very strong and predicts that p-adic length scales have satellite length scales given as multiples of n_F of fundamental p-adic length scale. $n_F = 2^{11}$ corresponds in TGD framework to a fundamental constant expressible as a combination of Kähler coupling strength, CP_2 radius and Planck length appearing in the expression for the tension of cosmic strings, and the powers of 2^{11} seem to be especially favored as values of n_a in living matter [9] .

3.6 How Planck constants are visible in Kähler action?

$\hbar(M^4)$ and $\hbar(CP_2)$ appear in the commutation and anticommutation relations of various superconformal algebras. Only the ratio of M^4 and CP_2 Planck constants appears in Kähler action and is due to the fact that the M^4 and CP_2 metrics of the imbedding space sector with given values of Planck constants are proportional to the corresponding Planck constants. This implies that Kähler function codes for radiative corrections to the classical action, which makes possible to consider the possibility that higher order radiative corrections to functional integral vanish as one might expect at quantum criticality. For a given p-adic length scale space-time sheets with all allowed values of Planck constants are possible. Hence the spectrum of quantum critical fluctuations could in the ideal case correspond to the spectrum of $\hbar$ coding for the scaled up values of Compton lengths and other quantal lengths and times. If so, large $\hbar$ phases could be crucial for understanding of quantum critical superconductors, in particular high T_c superconductors.

3.7 Could the dynamics of Kähler action predict the hierarchy of Planck constants?

The original justification for the hierarchy of Planck constants came from the indications that Planck constant could have large values in both astrophysical systems involving dark matter and also in biology. The realization of the hierarchy in terms of the singular coverings and possibly also factor spaces of CD and CP_2 emerged from consistency conditions. The formula for the Planck constant involves heuristic guess work and physical plausibility arguments. There are good arguments in favor of the hypothesis that only coverings are possible. Only a finite number of pages of the Big Book correspond to a given value of Planck constant, biological evolution corresponds to a gradual dispersion to the pages of the Big Book with larger Planck constant, and a connection with the hierarchy of infinite primes and p-adicization program based on the mathematical realization of finite measurement resolution emerges.

One can however ask whether this hierarchy could emerge directly from the basic quantum TGD rather than as a separate hypothesis. The following arguments suggest that this might be possible. One finds also a precise geometric interpretation of preferred extremal property interpreted as criticality in zero energy ontology.

3.7.1 1-1 correspondence between canonical momentum densities and time derivatives fails for Kähler action

The basic motivation for the geometrization program was the observation that canonical quantization for TGD fails. To see what is involved let us try to perform a canonical quantization in zero energy ontology at the 3-D surfaces located at the light-like boundaries of $CD \times CP_2$.

1. In canonical quantization canonical momentum densities $\pi_k^0 \equiv \pi_k = \partial L_K/\partial(\partial_0 h^k)$, where $\partial_0 h^k$ denotes the time derivative of imbedding space coordinate, are the physically natural quantities in terms of which to fix the initial values: once their value distribution is fixed also conserved charges are fixed. Also the weak form of electric-magnetic duality given by $J^{03}\sqrt{g_4} = 4\pi\alpha_K J_{12}$ and a mild generalization of this condition to be discussed below can be interpreted as a manner to fix the values of conserved gauge charges (not Noether charges) to their quantized values since Kähler magnetic flux equals to the integer giving the homology class of the (wormhole) throat. This condition alone need not characterize criticality, which requires an infinite number of deformations of X^4 for which the second variation of the Kähler action vanishes and implies infinite number conserved charges. This in fact gives hopes of replacing π_k with these conserved Noether charges.

2. Canonical quantization requires that $\partial_0 h^k$ in the energy is expressed in terms of π_k. The equation defining π_k in terms of $\partial_0 h^k$ is however highly non-linear although algebraic. By taking squares the equations reduces to equations for rational functions of $\partial_0 h^k$. $\partial_0 h^k$ appears in contravariant and covariant metric at most quadratically and in the induced Kähler electric field linearly and by multplying the equations by $det(g_4)^3$ one can transform the equations to a polynomial form so that in principle $\partial_0 h^k$ can obtained as a solution of polynomial equations.

3. One can always eliminate one half of the coordinates by choosing 4 imbedding space coordinates as the coordinates of the spacetime surface so that the initial value conditions reduce to those for the canonical momentum densities associated with the remaining four coordinates. For instance, for space-time surfaces representable as map $M^4 \rightarrow CP_2$ M^4 coordinates are natural and the time derivatives $\partial_0 s^k$ of CP_2 coordinates are multivalued. One would obtain four polynomial equations with $\partial_0 s^k$ as unknowns. In regions where CP_2 projection is 4-dimensional -in particular for the deformations of CP_2 vacuum extremals the natural coordinates are CP_2 coordinates and one can regard $\partial_0 m^k$ as unknows. For the deformations of cosmic strings, which are of form $X^4 = X^2 \times Y^2 \subset M^4 \times CP_2$, one can use coordinates of $M^2 \times S^2$, where S^2 is geodesic sphere as natural coordinates and regard as unknowns E^2 coordinates and remaining CP_2 coordinates.

4. One can imagine solving one of the four polynomials equations for time derivaties in terms of other obtaining N roots. Then one would substitute these roots to the remaining 3 conditions to obtain algebraic equations from which one solves then second variable. Obviously situation is very complex without additional symmetries. The criticality of the preferred extremals might however give additional conditions allowing simplifications. The reasons for giving up the canonical quantization program was following. For the vacuum extremals of Kähler action π_k are however identically vanishing and this means that there is an infinite number of value distributions for $\partial_0 h^k$. For small deformations of vacuum extremals one might however hope a finite

number of solutions to the conditions and thus finite number of space-time surfaces carrying same conserved charges.

If one assumes that physics is characterized by the values of the conserved charges one must treat the the many-valuedness of $\partial_0 h^k$. The most obvious guess is that one should replace the space of space-like 4-surfaces corresponding to different roots $\partial_0 h^k = F^k(\pi_l)$ with four-surfaces in the covering space of $CD \times CP_2$ corresponding to different branches of the many-valued function $\partial_0 h^k = F(\pi_l)$ co-inciding at the ends of CD.

3.7.2 Do the coverings forces by the many-valuedness of $\partial_0 h^k$ correspond to the coverings associated with the hierarchy of Planck constants?

The obvious question is whether this covering space actually corresponds to the covering spaces associated with the hierarchy of Planck constants. This would conform with quantum classical correspondence. The hierarchy of Planck constants and hierarchy of covering spaces was introduced to cure the failure of the perturbation theory at quantum level. At classical level the multivaluedness of $\partial_0 h^k$ means a failure of perturbative canonical quantization and forces the introduction of the covering spaces. The interpretation would be that when the density of matter becomes critical the space-time surface splits to several branches so that the density at each branches is sub-critical. It is of course not at all obvious whether the proposed structure of the Big Book is really consistent with this hypothesis and one also consider modifications of this structure if necessary. The manner to proceed is by making questions.

1. The proposed picture would give only single integer characterizing the covering. Two integers assignable to CD and CP_2 degrees of freedom are however needed. How these two coverings could emerge?

    (a) One should fix also the values of $\pi_k^n = \partial L_K/\partial h_n^k$, where n refers to space-like normal coordinate at the wormhole throats. If one requires that charges do not flow between regions with different signatures of the metric the natural condition is $\pi_k^n = 0$ and allows also multi-valued solution. Since wormhole throats carry magnetic charge and since weak form of electric-magnetic duality is assumed, one can assume that CP_2 projection is four-dimensional so that one can use CP_2 coordinates and regard $\partial_0 m^k$ as un-knows. The basic idea about topological condensation in turn suggests that M^4 projection can be assumed to be 4-D inside space-like 3-surfaces so that here $\partial_0 s^k$ are the unknowns. At partonic 2-surfaces one would have conditions for both π_k^0 and π_k^n. One might hope that the numbers of solutions are finite for preferred extremals because of their symmetries and given by n_a for $\partial_0 m^k$ and by n_b for $\partial_0 s^k$. The optimistic guess is that n_a and n_b corresponds to the numbers of sheets for singular coverings of CD and CP_2. The covering could be visualized as replacement of space-time surfaces with space-time surfaces which have $n_a n_b$ branches. n_b branches would degenerate to single branch at the ends of diagrams of the generaled Feynman graph and n_a branches would degenerate to single one at wormhole throats.

    (b) This picture is not quite correct yet. The fixing of π_k^0 and π_k^n should relate closely to the effective 2-dimensionality as an additional condition perhaps crucial for criticality. One could argue that both π_k^0 and π_k^n must be fixed at X^3 and X_l^3 in order to effectively bring in dynamics in two directions so that X^3 could be interpreted as a an orbit of partonic 2-surface in space-like direction and X_l^3 as its orbit in light-like direction. The additional conditions could be seen as gauge conditions made possible by symplectic and Kac-Moody type conformal symmetries. The conditions for π_0^k would give n_b branches in CP_2 degrees of freedom and the conditions for π_k^n would split each of these branches to n_a branches.

    (c) The existence of these two kinds of conserved charges (possibly vanishing for π_k^n) could relate also very closely to the slicing of the space-time sheets by string world sheets and partonic 2-surfaces.

2. Should one then treat these branches as separate space-time surfaces or as a single space-time surface? The treatment as a single surface seems to be the correct thing to do. Classically the conserved changes would be $n_a n_b$ times larger than for single branch. Kähler action need not

(but could!) be same for different branches but the total action is $n_a n_b$ times the average action and this effectively corresponds to the replacement of the $\hbar_0/g_K^2$ factor of the action with $\hbar/g_K^2$, $r \equiv \hbar/\hbar_0 = n_a n_b$. Since the conserved quantum charges are proportional to $\hbar$ one could argue that $r = n_a n_b$ tells only that the charge conserved charge is $n_a n_b$ times larger than without multi-valuedness. $\hbar$ would be only effectively $n_a n_b$ fold. This is of course poor man's argument but might catch something essential about the situation.

3. How could one interpret the condition $J^{03}\sqrt{g_4} = 4\pi\alpha_K J_{12}$ and its generalization to be discussed below in this framework? The first observation is that the total Kähler electric charge is by $\alpha_K \propto 1/(n_a n_b)$ same always. The interpretation would be in terms of charge fractionization meaning that each branch would carry Kähler electric charge $Q_K = ng_K/n_a n_b$. I have indeed suggested explanation of charge fractionization and quantum Hall effect based on this picture.

4. The vision about the hierarchy of Planck constants involves also assumptions about imbedding space metric. The assumption that the M^4 covariant metric is proportional to $\hbar^2$ follows from the physical idea about $\hbar$ scaling of quantum lengths as what Compton length is. One can always introduce scaled M^4 coordinates bringing M^4 metric into the standard form by scaling up the M^4 size of CD. It is not clear whether the scaling up of CD size follows automatically from the proposed scenario. The basic question is why the M^4 size scale of the critical extremals must scale like $n_a n_b$? This should somehow relate to the weak self-duality conditions implying that Kähler field at each branch is reduced by a factor $1/r$ at each branch. Field equations should posses a dynamical symmetry involving the scaling of CD by integer k and $J^{0\beta}\sqrt{g_4}$ and $J^{n\beta}\sqrt{g_4}$ by $1/k$. The scaling of CD should be due to the scaling up of the M^4 time interval during which the branched light-like 3-surface returns back to a non-branched one.

5. The proposed view about hierarchy of Planck constants is that the singular coverings reduce to single-sheeted coverings at $M^2 \subset M^4$ for CD and to $S^2 \subset CP_2$ for CP_2. Here S^2 is any homologically trivial geodesic sphere of CP_2 and has vanishing Kähler form. Weak self-duality condition is indeed consistent with any value of $\hbar$ and impies that the vacuum property for the partonic 2-surface implies vacuum property for the entire space-time sheet as holography indeed requires. This condition however generalizes. In weak self-duality conditions the value of $\hbar$ is free for any 2-D Lagrangian sub-manifold of CP_2.

   The branching along M^2 would mean that the branches of preferred extremals always collapse to single branch when their M^4 projection belongs to M^2. Magnetically charged light-light-like throats cannot have M^4 projection in M^2 so that self-duality conditions for different values of $\hbar$ do not lead to inconsistencies. For spacelike 3-surfaces at the boundaries of CD the condition would mean that the M^4 projection becomes light-like geodesic. Straight cosmic strings would have M^2 as M^4 projection. Also CP_2 type vacuum extremals for which the random light-like projection in M^4 belongs to M^2 would represent this of situation. One can ask whether the degeneration of branches actually takes place along any string like object $X^2 \times Y^2$, where X^2 defines a minimal surface in M^4. For these the weak self-duality condition would imply $\hbar = \infty$ at the ends of the string. It is very plausible that string like objects feed their magnetic fluxes to larger space-times sheets through wormhole contacts so that these conditions are not encountered.

3.7.3 Connection with the criticality of preferred extremals

Also a connection with quantum criticality and the criticality of the preferred extremals suggests itself. Criticality for the preferred extremals must be a property of space-like 3-surfaces and light-like 3-surfaces with degenerate 4-metric and the degeneration of the $n_a n_b$ branches of the space-time surface at the its ends and at wormhole throats is exactly what happens at criticality. For instance, in catastrophe theory roots of the polynomial equation giving extrema of a potential as function of control parameters co-incide at criticality. If this picture is correct the hierarchy of Planck constants would be an outcome of criticality and of preferred extremal property and preferred extremals would be just those multi-branched space-time surfaces for which branches co-incide at the the boundaries of $CD \times CP_2$ and at the throats.

4 Number theoretic compactification and $M^8 - H$ duality

This section summarizes the basic vision about number theoretic compactification reducing the classical dynamics to number theory. In strong form $M^8 - H$ duality boils down to the assumption that space-time surfaces can be regarded either as surfaces of H or as surfaces of M^8 composed of hyper-quaternionic and co-hyper-quaternionic regions identifiable as regions of space-time possessing Minkowskian *resp.* Euclidian signature of the induced metric.

4.1 Basic idea behind $M^8 - M^4 \times CP_2$ duality

The hopes of giving $M^4 \times CP_2$ hyper-octonionic structure are meager. This circumstance forces to ask whether four-surfaces $X^4 \subset M^8$ could under some conditions define 4-surfaces in $M^4 \times CP_2$ indirectly so that the spontaneous compactification of super string models would correspond in TGD to two different manners to interpret the space-time surface. The following arguments suggest that this is indeed the case.

The hard mathematical fact behind number theoretical compactification is that the quaternionic sub-algebras of octonions with fixed complex structure (that is complex sub-space) are parameterized by CP_2 just as the complex planes of quaternion space are parameterized by $CP_1 = S^2$. Same applies to hyper-quaternionic sub-spaces of hyper-octonions. $SU(3)$ would thus have an interpretation as the isometry group of CP_2, as the automorphism sub-group of octonions, and as color group.

1. The space of complex structures of the octonion space is parameterized by S^6. The subgroup $SU(3)$ of the full automorphism group G_2 respects the a priori selected complex structure and thus leaves invariant one octonionic imaginary unit, call it e_1. Hyper-quaternions can be identified as $U(2)$ Lie-algebra but it is obvious that hyper-octonions do not allow an identification as $SU(3)$ Lie algebra. Rather, octonions decompose as $1 \oplus 1 \oplus 3 \oplus \overline{3}$ to the irreducible representations of $SU(3)$.

2. Geometrically the choice of a preferred complex (quaternionic) structure means fixing of complex (quaternionic) sub-space of octonions. The fixing of a hyper-quaternionic structure of hyper-octonionic M^8 means a selection of a fixed hyper-quaternionic sub-space $M^4 \subset M^8$ implying the decomposition $M^8 = M^4 \times E^4$. If M^8 is identified as the tangent space of $H = M^4 \times CP_2$, this decomposition results naturally. It is also possible to select a fixed hyper-complex structure, which means a further decomposition $M^4 = M^2 \times E^2$.

3. The basic result behind number theoretic compactification and $M^8 - H$ duality is that hyper-quaternionic sub-spaces $M^4 \subset M^8$ containing a fixed hyper-complex sub-space $M^2 \subset M^4$ or its light-like line $M_\pm$ are parameterized by CP_2. The choices of a fixed hyper-quaternionic basis $1, e_1, e_2, e_3$ with a fixed complex sub-space (choice of e_1) are labeled by $U(2) \subset SU(3)$. The choice of e_2 and e_3 amounts to fixing $e_2 \pm \sqrt{-1}e_3$, which selects the $U(2) = SU(2) \times U(1)$ subgroup of $SU(3)$. $U(1)$ leaves 1 invariant and induced a phase multiplication of e_1 and $e_2 \pm e_3$. $SU(2)$ induces rotations of the spinor having e_2 and e_3 components. Hence all possible completions of $1, e_1$ by adding e_2, e_3 doublet are labeled by $SU(3)/U(2) = CP_2$.

4. Space-time surface $X^4 \subset M^8$ is by the standard definition hyper-quaternionic if the tangent spaces of X^4 are hyper-quaternionic planes. Co-hyper-quaternionicity means the same for normal spaces. The presence of fixed hyper-complex structure means at space-time level that the tangent space of X^4 contains fixed M^2 at each point. Under this assumption one can map the points $(m, e) \in M^8$ to points $(m, s) \in H$ by assigning to the point (m, e) of X^4 the point (m, s), where $s \in CP_2$ characterize $T(X^4)$ as hyper-quaternionic plane. This definition is not the only one and even the appropriate one in TGD context the replacement of the tangent plane with the 4-D plane spanned by modified gamma matrices defined by Kähler action is a more natural choice. This plane is not parallel to tangent plane in general. In the sequel $T(X^4)$ denotes the preferred 4-plane which co-incides with tangent plane of X^4 only if the action defining modified gamma matrices is 4-volume.

5. The choice of M^2 can be made also local in the sense that one has $T(X^4) \supset M^2(x) \subset M^4 \subset H$. It turns out that strong form of number theoretic compactification requires this kind of generalization. In this case one must be able to fix the convention how the point of CP_2 is

assigned to a hyper-quaternionic plane so that it applies to all possible choices of $M^2 \subset M^4$. Since $SO(3)$ hyper-quaternionic rotation relates the hyper-quaternionic planes to each other, the natural assumption is hyper-quaternionic planes related by $SO(3)$ rotation correspond to the same point of CP_2. Under this assumption it is possible to map hyper-quaternionic surfaces of M^8 for which $M^2 \subset M^4$ depends on point of X^4 to H.

4.2 Hyper-octonionic Pauli "matrices" and modified definition of hyper-quaternionicity

Hyper-octonionic Pauli matrices suggest an interesting possibility to define precisely what hyper-quaternionicity means at space-time level (for background see [29]).

1. According to the standard definition space-time surface X^4 is hyper-quaternionic if the tangent space at each point of X^4 in $X^4 \subset M^8$ picture is hyper-quaternionic. What raises worries is that this definition involves in no manner the action principle so that it is far from obvious that this identification is consistent with the vacuum degeneracy of Kähler action. It also unclear how one should formulate hyper-quaternionicity condition in $X^4 \subset M^4 \times CP_2$ picture.

2. The idea is to map the modified gamma matrices $\Gamma^\alpha = \frac{\partial L_K}{\partial h^k_\alpha}\Gamma^k$, $\Gamma_k = e^A_k\gamma_A$, to hyper-octonionic Pauli matrices σ^α by replacing γ_A with hyper-octonion unit. Hyper-quaternionicity would state that the hyper-octonionic Pauli matrices σ^α obtained in this manner span complexified quaternion sub-algebra at each point of space-time. These conditions would provide a number theoretic manner to select preferred extremals of Kähler action. Remarkably, this definition applies both in case of M^8 and $M^4 \times CP_2$.

3. Modified Pauli matrices span the tangent space of X^4 if the action is four-volume because one has $\frac{\partial L_K}{\partial h^k_\alpha} = \sqrt{g}g^{\alpha\beta}\partial h^l_\beta h_{kl}$. Modified gamma matrices reduce to ordinary induced gamma matrices in this case: 4-volume indeed defines a super-conformally symmetric action for ordinary gamma matrices since the mass term of the Dirac action given by the trace of the second fundamental form vanishes for minimal surfaces.

4. For Kähler action the hyper-quaternionic sub-space does not coincide with the tangent space since $\frac{\partial L_K}{\partial h^k_\alpha}$ contains besides the gravitational contribution coming from the induced metric also the "Maxwell contribution" from the induced Kähler form not parallel to space-time surface. Modified gamma matrices are required by super conformal symmetry for the extremals of Kähler action and they also guarantee that vacuum extremals defined by surfaces in $M^4 \times Y^2$, Y^2 a Lagrange sub-manifold of CP_2, are trivially hyper-quaternionic surfaces. The modified definition of hyper-quaternionicity does not affect in any manner $M^8 \leftrightarrow M^4 \times CP_2$ duality allowing purely number theoretic interpretation of standard model symmetries.

A side comment not strictly related to hyper-quaternionicity is in order. The anticommutators of the modified gamma matrices define an effective Riemann metric and one can assign to it the counterparts of Riemann connection, curvature tensor, geodesic line, volume, etc... One would have two different metrics associated with the space-time surface. Only if the action defining space-time surface is identified as the volume in the ordinary metric, these metrics are equivalent. The index raising for the effective metric could be defined also by the induced metric and it is not clear whether one can define Riemann connection also in this case. Could this effective metric have concrete physical significance and play a deeper role in quantum TGD? For instance, AdS-CFT duality leads to ask whether interactions be coded in terms of the gravitation associated with the effective metric.

4.3 Minimal form of $M^8 - H$ duality

The basic problem in the construction of quantum TGD has been the identification of the preferred extremals of Kähler action playing a key role in the definition of the theory. The most elegant manner to do this is by fixing the 4-D tangent space $T(X^4(X^3_l))$ of $X^4(X^3_l)$ at each point of X^3_l so that the boundary value problem is well defined. What I called number theoretical compactification allows to achieve just this although I did not fully realize this in the original vision. The minimal picture is following.

1. The basic observations are following. Let M^8 be endowed with hyper-octonionic structure. For hyper-quaternionic space-time surfaces in M^8 tangent spaces are by definition hyper-quaternionic. If they contain a preferred plane $M^2 \subset M^4 \subset M^8$ in their tangent space, they can be mapped to 4-surfaces in $M^4 \times CP_2$. The reason is that the hyper-quaternionic planes containing preferred the hyper-complex plane M^2 of $M_\pm \subset M^2$ are parameterized by points of CP_2. The map is simply $(m,e) \rightarrow (m, s(m,e))$, where m is point of M^4, e is point of E^4, and $s(m,2)$ is point of CP_2 representing the hyperquaternionic plane. The inverse map assigns to each point (m,s) in $M^4 \times CP_2$ point m of M^4, undetermined point e of E^4 and 4-D plane. The requirement that the distribution of planes containing the preferred M^2 or $M_\pm$ corresponds to a distribution of planes for 4-D surface is expected to fix the points e. The physical interpretation of M^2 is in terms of plane of non-physical polarizations so that gauge conditions have purely number theoretical interpretation.

2. In principle, the condition that $T(X^4)$ contains M^2 can be replaced with a weaker condition that either of the two light-like vectors of M^2 is contained in it since already this condition assigns to $T(X^4)$ M^2 and the map $H \rightarrow M^8$ becomes possible. Only this weaker form applies in the case of massless extremals [3] as will be found.

3. The original idea was that hyper-quaternionic 4-surfaces in M^8 containing $M^2 \subset M^4$ in their tangent space could correspond to preferred extremals of Kähler action. This condition does not seem to be consistent with what is known about the extremals of Kähler action. The weaker form of the hypothesis is that hyper-quaternionicity holds only for 4-D tangent spaces of $X^3_l \subset H = M^4 \times CP_2$ identified as wormhole throats or boundary components lifted to 3-surfaces in 8-D tangent space M^8 of H. The minimal hypothesis would be that only $T(X^4(X^3_l))$ at X^3_l is associative that is hyper-quaternionic for fixed M^2. $X^3_l \subset M^8$ and $T(X^4(X^3_l))$ at X^3_l can be mapped to $X^3_l \subset H$ if tangent space contains also $M_\pm \subset M^2$ or $M^2 \subset M^4 \subset M^8$ itself having interpretation as preferred hyper-complex plane. This condition is not satisfied by all surfaces X^3_l as is clear from the fact that the inverse map involves local E^4 translation. The requirements that the distribution of hyper-quaternionic planes containing M^2 corresponds to a distribution of 4-D tangent planes should fix the E^4 translation to a high degree.

4. A natural requirement is that the image of $X^3_l \subset H$ in M^8 is light-like. The condition that the determinant of induced metric vanishes gives an additional condition reducing the number of free parameters by one. This condition cannot be formulated as a condition on CP_2 coordinate characterizing the hyper-quaternionic plane. Since M^4 projections are same for the two representations, this condition is satisfied if the contributions from CP_2 and E^4 and projections to the induced metric are identical: $s_{kl}\partial_\alpha s^k \partial_\beta s^l = e_{kl}\partial_\alpha e^k \partial_\beta e^l$. This condition means that only a subset of light-like surfaces of M^8 are realized physically. One might argue that this is as it must be since the volume of E^4 is infinite and that of CP_2 finite: only an infinitesimal portion of all possible light-like 3-surfaces in M^8 can can have H counterparts. The conclusion would be that number theoretical compactification is 4-D isometry between $X^4 \subset H$ and $X^4 \subset M^8$ at X^3_l. This unproven conjecture is unavoidable.

5. $M^2 \subset T(X^4(X^3_l))$ condition fixes $T(X^4(X^3_l))$ in the generic case by extending the tangent space of X^3_l, and the construction of configuration space spinor structure fixes boundary conditions completely by additional conditions necessary when X^3_l corresponds to a light-like 3 surfaces defining wormhole throat at which the signature of induced metric changes. What is especially beautiful that only the data in $T(X^4(X^3_l))$ at X^3_l is needed to calculate the vacuum functional of the theory as Dirac determinant: the only remaining conjecture (strictly speaking un-necessary but realistic looking) is that this determinant gives exponent of Kähler action for the preferred extremal and there are excellent hopes for this by the structure of the basic construction.

The basic criticism relates to the condition that light-like 3-surfaces are mapped to light-like 3-surfaces guaranteed by the condition that $M^8 - H$ duality is isometry at X^3_l.

4.4 Strong form of $M^8 - H$ duality

The proposed picture is the minimal one. One can of course ask whether the original much stronger conjecture that the preferred extrema of Kähler action correspond to hyper-quaternionic surfaces could make sense in some form. One can also wonder whether one could allow the choice of the plane M^2 of non-physical polarization to be local so that one would have $M^2(x) \subset M^4 \subset M^4 \times E^4$, where M^4 is fixed hyper-quaternionic sub-space of M^8 and identifiable as M^4 factor of H.

1. If M^2 is same for all points of X_l^3, the inverse map $X_l^3 \subset H \rightarrow X_l^3 \subset M^8$ is fixed apart from possible non-uniquencess related to the local translation in E^4 from the condition that hyper-quaternionic planes represent light-like tangent 4-planes of light-like 3-surfaces. The question is whether not only X_l^3 but entire four-surface $X^4(X_l^3)$ could be mapped to the tangent space of M^8. By selecting suitably the local E^4 translation one might hope of achieving the achieving this. The conjecture would be that the preferred extrema of Kähler action are those for which the distribution integrates to a distribution of tangent planes.

2. There is however a problem. What is known about extremals of Kähler action is not consistent with the assumption that fixed M^2 of $M_\pm \subset M^2$is contained in the tangent space of X^4. This suggests that one should relax the condition that $M^2 \subset M^4 \subset M^8$ is a fixed hyper-complex plane associated with the tangent space or normal space X^4 and allow M^2 to vary from point to point so that one would have $M^2 = M^2(x)$. In $M^8 \rightarrow H$ direction the justification comes from the observation (to be discussed below) that it is possible to uniquely fix the convention assigning CP_2 point to a hyper-quaternionic plane containing varying hyper-complex plane $M^2(x) \subset M^4$.

   Number theoretic compactification fixes naturally $M^4 \subset M^8$ so that it applies to any $M^2(x) \subset M^4$. Under this condition the selection is parameterized by an element of $SO(3)/SO(2) = S^2$. Note that M^4 projection of X^4 would be at least 2-dimensional in hyper-quaternionic case. In co-hyper-quaternionic case E^4 projection would be at least 2-D. $SO(2)$ would act as a number theoretic gauge symmetry and the $SO(3)$ valued chiral field would approach to constant at X_l^3 invariant under global $SO(2)$ in the case that one keeps the assumption that M^2 is fixed ad X_l^3.

3. This picture requires a generalization of the map assigning to hyper-quaternionic plane a point of CP_2 so that this map is defined for all possible choices of $M^2 \subset M^4$. Since the $SO(3)$ rotation of the hyper-quaternionic unit defining M^2 rotates different choices parameterized by S^2 to each other, a natural assumption is that the hyper-quaternionic planes related by $SO(3)$ rotation correspond to the same point of CP_2. Denoting by M^2 the standard representative of M^2, this means that for the map $M^8 \rightarrow H$ one must perform $SO(3)$ rotation of hyper-quaternionic plane taking $M^2(x)$ to M^2 and map the rotated plane to CP_2 point. In $M^8 \rightarrow H$ case one must first map the point of CP_2 to hyper-quaternionic plane and rotate this plane by a rotation taking $M^2(x)$ to M^2.

4. In this framework local M^2 can vary also at the surfaces X_l^3, which considerably relaxes the boundary conditions at wormhole throats and light-like boundaries and allows much more general variety of light-like 3-surfaces since the basic requirement is that M^4 projection is at least 1-dimensional. The physical interpretation would be that a local choice of the plane of non-physical polarizations is possible everywhere in $X^4(X_l^3)$. This does not seem to be in any obvious conflict with physical intuition.

These observation provide support for the conjecture that (classical) $S^2 = SO(3)/SO(2)$ conformal field theory might be relevant for (classical) TGD.

1. General coordinate invariance suggests that the theory should allow a formulation using any light-like 3-surface X^3 inside $X^4(X_l^3)$ besides X_l^3 identified as union of wormhole throats and boundary components. For these surfaces the element $g(x) \in SO(3)$ would vary also at partonic 2-surfaces X^2 defined as intersections of $\delta CD \times CP_2$ and X^3 (here CD denotes causal diamond defined as intersection of future and past directed light-cones). Hence one could have $S^2 = SO(3)/SO(2)$ conformal field theory at X^2 (regarded as quantum fluctuating so that also $g(x)$ varies) generalizing to WZW model for light-like surfaces X^3.

2. The presence of E^4 factor would extend this theory to a classical $E^4 \times S^2$ WZW model bringing in mind string model with 6-D Euclidian target space extended to a model of light-like 3-surfaces. A further extension to X^4 would be needed to integrate the WZW models associated with 3-surfaces to a full 4-D description. General Coordinate Invariance however suggests that X_l^3 description is enough for practical purposes.

3. The choices of $M^2(x)$ in the interior of X^3_l is dictated by dynamics and the first optimistic conjecture is that a classical solution of $SO(3)/SO(2)$ Wess-Zumino-Witten model obtained by coupling $SO(3)$ valued field to a covariantly constant $SO(2)$ gauge potential characterizes the choice of $M^2(x)$ in the interior of $M^8 \supset X^4(X^3_l) \subset H$ and thus also partially the structure of the preferred extremal. Second optimistic conjecture is that the Kähler action involving also E^4 degrees of freedom allows to assign light-like 3-surface to light-like 3-surface.

4. The best that one can hope is that $M^8 - H$ duality could allow to transform the extremely non-linear classical dynamics of TGD to a generalization of WZW-type model. The basic problem is to understand how to characterize the dynamics of CP_2 projection at each point.

In H picture there are two basic types of vacuum extremals: CP_2 type extremals representing elementary particles and vacuum extremals having CP_2 projection which is at most 2-dimensional Lagrange manifold and representing say hadron. Vacuum extremals can appear only as limiting cases of preferred extremals which are non-vacuum extremals. Since vacuum extremals have so decisive role in TGD, it is natural to requires that this notion makes sense also in M^8 picture. In particular, the notion of vacuum extremal makes sense in M^8.

This requires that Kähler form exist in M^8. E^4 indeed allows full S^2 of covariantly constant Kähler forms representing quaternionic imaginary units so that one can identify Kähler form and construct Kähler action. The obvious conjecture is that hyper-quaternionic space-time surface is extremal of this Kähler action and that the values of Kähler actions in M^8 and H are identical. The elegant manner to achieve this, as well as the mapping of vacuum extremals to vacuum extremals and the mapping of light-like 3-surfaces to light-like 3-surfaces is to assume that $M^8 - H$ duality is Kähler isometry so that induced Kähler forms are identical.

This picture contains many speculative elements and some words of warning are in order.

1. Light-likeness conjecture would boil down to the hypothesis that $M^8 - H$ correspondence is Kähler isometry so that the metric and Kähler form of X^4 induced from M^8 and H would be identical. This would guarantee also that Kähler actions for the preferred extremal are identical. This conjecture is beautiful but strong.

2. The slicing of $X^4(X^3_l)$ by light-like 3-surfaces is very strong condition on the classical dynamics of Kähler action and does not make sense for pieces of CP_2 type vacuum extremals.

4.4.1 Minkowskian-Euclidian $\leftrightarrow$ associative–co-associative

The 8-dimensionality of M^8 allows to consider both associativity (hyper-quaternionicity) of the tangent space and associativity of the normal space- let us call this co-assosiativity of tangent space- as alternative options. Both options are needed as has been already found. Since space-time surface decomposes into regions whose induced metric possesses either Minkowskian or Euclidian signature, there is a strong temptation to propose that Minkowskian regions correspond to associative and Euclidian regions to co-associative regions so that space-time itself would provide both the description and its dual.

The proposed interpretation of conjectured associative-co-associative duality relates in an interesting manner to p-adic length scale hypothesis selecting the primes $p \simeq 2^k$, k positive integer as preferred p-adic length scales. $L_p \propto \sqrt{p}$ corresponds to the p-adic length scale defining the size of the space-time sheet at which elementary particle represented as CP_2 type extremal is topologically condensed and is of order Compton length. $L_k \propto \sqrt{k}$ represents the p-adic length scale of the wormhole contacts associated with the CP_2 type extremal and CP_2 size is the natural length unit now. Obviously the quantitative formulation for associative-co-associative duality would be in terms $p \rightarrow k$ duality.

4.4.2 Are the known extremals of Kähler action consistent with the strong form of $M^8 - H$ duality

It is interesting to check whether the known extremals of Kähler action [3] are consistent with strong form of $M^8 - H$ duality assuming that M^2 or its light-like ray is contained in $T(X^4)$ or normal space.

1. CP_2 type vacuum extremals correspond cannot be hyper-quaternionic surfaces but co-hyper-quaternionicity is natural for them. In the same manner canonically imbedded M^4 can be only hyper-quaternionic.

2. String like objects are associative since tangent space obviously contains $M^2(x)$. Objects of form $M^1 \times X^3 \subset M^4 \times CP_2$ do not have M^2 either in their tangent space or normal space in H. So that the map from $H \rightarrow M^8$ is not well defined. There are no known extremals of Kähler action of this type. The replacement of M^1 random light-like curve however gives vacuum extremal with vanishing volume, which need not mean physical triviality since fundamental objects of the theory are light-like 3-surfaces.

3. For canonically imbedded CP_2 the assignment of $M^2(x)$ to normal space is possible but the choice of $M^2(x) \subset N(CP_2)$ is completely arbitrary. For a generic CP_2 type vacuum extremals M^4 projection is a random light-like curve in $M^4 = M^1 \times E^3$ and $M^2(x)$ can be defined uniquely by the normal vector $n \in E^3$ for the local plane defined by the tangent vector dx^μ/dt and acceleration vector d^2x^μ/dt^2 assignable to the orbit.

4. Consider next massless extremals. Let us fix the coordinates of X^4 as $(t, z, x, y) = (m^0, m^2, m^1, m^2)$. For simplest massless extremals CP_2 coordinates are arbitrary functions of variables $u = k \cdot m = t - z$ and $v = \epsilon \cdot m = x$, where $k = (1, 1, 0, 0)$ is light-like vector of M^4 and $\epsilon = (0, 0, 1, 0)$ a polarization vector orthogonal to it. Obviously, the extremals defines a decomposition $M^4 = M^2 \times E^2$. Tangent space is spanned by the four H-vectors $\nabla_\alpha h^k$ with M^4 part given by $\nabla_\alpha m^k = \delta^k_\alpha$ and CP_2 part by $\nabla_\alpha s^k = \partial_u s^k k_\alpha + \partial_v s^k \epsilon_\alpha$.

   The normal space cannot contain M^4 vectors since the M^4 projection of the extremal is M^4. To realize hyper-quaternionic representation one should be able to from these vector two vectors of M^2, which means linear combinations of tangent vectors for which CP_2 part vanishes. The vector $\partial_t h^k - \partial_z h^k$ has vanishing CP_2 part and corresponds to M^4 vector $(1, -1, 0, 0)$ fix assigns to each point the plane M^2. To obtain M^2 one would need $(1, 1, 0, 0)$ too but this is not possible. The vector $\partial_y h^k$ is M^4 vector orthogonal to ϵ but M^2 would require also $(1, 0, 0, 0)$. The proposed generalization of massless extremals allows the light-like line $M_\pm$ to depend on point of M^4 [3] , and leads to the introduction of Hamilton-Jacobi coordinates involving a local decomposition of M^4 to $M^2(x)$ and its orthogonal complement with light-like coordinate lines having interpretation as curved light rays. $M^2(x) \subset T(X^4)$ assumption fails fails also for vacuum extremals of form $X^1 \times X^3 \subset M^4 \times CP_2$, where X^1 is light-like random curve. In the latter case, vacuum property follows from the vanishing of the determinant of the induced metric.

5. The deformations of string like objects to magnetic flux quanta are basic conjectural extremals of Kähler action and the proposed picture supports this conjecture. In hyper-quaternionic case the assumption that local 4-D plane of X^3 defined by modified gamma matrices contains $M^2(x)$ but that $T(X^3)$ does not contain it, is very strong. It states that $T(X^4)$ at each point can be regarded as a product $M^2(x) \times T^2$, $T^2 \subset T(CP_2)$, so that hyper-quaternionic X^4 would be a collection of Cartesian products of infinitesimal 2-D planes $M^2(x) \subset M^4$ and $T^2(x) \subset CP_2$. The extremals in question could be seen as local variants of string like objects $X^2 \times Y^2 \subset M^4 \times CP_2$, where X^2 is minimal surface and Y^2 holomorphic surface of CP_2. One can say that X^2 is replaced by a collection of infinitesimal pieces of $M^2(x)$ and Y^2 with similar pieces of homologically non-trivial geodesic sphere $S^2(x)$ of CP_2, and the Cartesian products of these pieces are glued together to form a continuous surface defining an extremal of Kähler action. Field equations would pose conditions on how $M^2(x)$ and $S^2(x)$ can depend on x. This description applies to magnetic flux quanta, which are the most important must-be extremals of Kähler action.

4.4.3 Geometric interpretation of strong $M^8 - H$ duality

In the proposed framework $M^8 - H$ duality would have a purely geometric meaning and there would nothing magical in it.

1. $X^4(X^3_l) \subset H$ could be seen a curve representing the orbit of a light-like 3-surface defining a 4-D surface. The question is how to determine the notion of tangent vector for the orbit of X^3_l. Intuitively tangent vector is a one-dimensional arrow tangential to the curve at point X^3_l. The

identification of the hyper-quaternionic surface $X^4(X_l^3) \subset M^8$ as tangent vector conforms with this intuition.

2. One could argue that M^8 representation of space-time surface is kind of chart of the real space-time surface obtained by replacing real curve by its tangent line. If so, one cannot avoid the question under which conditions this kind of chart is faithful. An alternative interpretation is that a representation making possible to realize number theoretical universality is in question.

3. An interesting question is whether $X^4(X_l^3)$ as orbit of light-like 3-surface is analogous to a geodesic line -possibly light-like- so that its tangent vector would be parallel translated in the sense that $X^4(X^3)$ for any light-like surface at the orbit is same as $X^4(X_l^3)$. This would give justification for the possibility to interpret space-time surfaces as a geodesic of configuration space: this is one of the first -and practically forgotten- speculations inspired by the construction of configuration space geometry. The light-likeness of the geodesic could correspond at the level of X^4 the possibility to decompose the tangent space to a direct sum of two light-like spaces and 2-D transversal space producing the foliation of X^4 to light-like 3-surfaces X_l^3 along light-like curves.

4. M^8-H duality would assign to X_l^3 classical orbit and its tangent vector at X_l^3 as a generalization of Bohr orbit. This picture differs from the wave particle duality of wave mechanics stating that once the position of particle is known its momentum is completely unknown. The outcome is however the same: for X_l^3 corresponding to wormhole throats and light-like boundaries of X^4, canonical momentum densities in the normal direction vanish identically by conservation laws and one can say that the the analog of (q,p) phase space as the space carrying wave functions is replaced with the analog of subspace consisting of points $(q,0)$. The dual description in M^8 would not be analogous to wave functions in momentum space space but to those in the space of unique tangents of curves at their initial points.

4.4.4 The Kähler and spinor structures of M^8

If one introduces M^8 as dual of H, one cannot avoid the idea that hyper-quaternionic surfaces obtained as images of the preferred extremals of Kähler action in H are also extremals of M^8 Kähler action with same value of Kähler action. As found, this leads to the conclusion that the$M^8 - H$ duality is Kähler isometry. Coupling of spinors to Kähler potential is the next step and this in turn leads to the introduction of spinor structure so that quantum TGD in H should have full M^8 dual.

There are strong physical constraints on M^8 dual and they could kill the hypothesis. The basic constraint to the spinor structure of M^8 is that it reproduces basic facts about electro-weak interactions. This includes neutral electro-weak couplings to quarks and leptons identified as different H-chiralities and parity breaking.

1. By the flatness of the metric of E^4 its spinor connection is trivial. E^4 however allows full S^2 of covariantly constant Kähler forms so that one can accommodate free independent Abelian gauge fields assuming that the independent gauge fields are orthogonal to each other when interpreted as realizations of quaternionic imaginary units.

2. One should be able to distinguish between quarks and leptons also in M^8, which suggests that one introduce spinor structure and Kähler structure in E^4. The Kähler structure of E^4 is unique apart form $SO(3)$ rotation since all three quaternionic imaginary units and the unit vectors formed from them allow a representation as an antisymmetric tensor. Hence one must select one preferred Kähler structure, that is fix a point of S^2 representing the selected imaginary unit. It is natural to assume different couplings of the Kähler gauge potential to spinor chiralities representing quarks and leptons: these couplings can be assumed to be same as in case of H.

3. Electro-weak gauge potential has vectorial and axial parts. Em part is vectorial involving coupling to Kähler form and Z^0 contains both axial and vector parts. The free Kähler forms could thus allow to produce M^8 counterparts of these gauge potentials possessing same couplings as their H counterparts. This picture would produce parity breaking in M^8 picture correctly.

4. Only the charged parts of classical electro-weak gauge fields would be absent. This would conform with the standard thinking that charged classical fields are not important. The predicted

classical W fields is one of the basic distinctions between TGD and standard model and in this framework. A further prediction is that this distinction becomes visible only in situations, where H picture is necessary. This is the case at high energies, where the description of quarks in terms of $SU(3)$ color is convenient whereas $SO(4)$ QCD would require large number of E^4 partial waves. At low energies large number of $SU(3)$ color partial waves are needed and the convenient description would be in terms of $SO(4)$ QCD. Proton spin crisis might relate to this.

5. Also super-symmetries of quantum TGD crucial for the construction of configuration space geometry force this picture. In the absence of coupling to Kähler gauge potential all constant spinor fields and their conjugates would generate super-symmetries so that M^8 would allow $N = 8$ super-symmetry. The introduction of the coupling to Kähler gauge potential in turn means that all covariantly constant spinor fields are lost. Only the representation of all three neutral parts of electro-weak gauge potentials in terms of three independent Kähler gauge potentials allows right-handed neutrino as the only super-symmetry generator as in the case of H.

6. The $SO(3)$ element characterizing $M^2(x)$ is fixed apart from a local $SO(2)$ transformation, which suggests an additional $U(1)$ gauge field associated with $SO(2)$ gauge invariance and representable as Kähler form corresponding to a quaternionic unit of E^4. A possible identification of this gauge field would be as a part of electro-weak gauge field.

4.4.5 M^8 dual of configuration space geometry and spinor structure?

If one introduces M^8 spinor structure and preferred extremals of M^8 Kähler action, one cannot avoid the question whether it is possible or useful to formulate the notion of configuration space geometry and spinor structure for light-like 3-surfaces in M^8 using the exponent of Kähler action as vacuum functional.

1. The isometries of the configuration space in M^8 and H formulations would correspond to symplectic transformation of $\delta M^4_\pm \times E^4$ and $\delta M^4_\pm \times CP_2$ and the Hamiltonians involved would belong to the representations of $SO(4)$ and $SU(3)$ with 2-dimensional Cartan sub-algebras. In H picture color group would be the familiar $SU(3)$ but in M^8 picture it would be $SO(4)$. Color confinement in both $SU(3)$ and $SO(4)$ sense could allow these two pictures without any inconsistency.

2. For $M^4 \times CP_2$ the two spin states of covariantly constant right handed neutrino and antineutrino spinors generate super-symmetries. This super-symmetry plays an important role in the proposed construction of configuration space geometry. As found, this symmetry would be present also in M^8 formulation so that the construction of M^8 geometry should reduce more or less to the replacement of CP_2 Hamiltonians in representations of $SU(3)$ with E^4 Hamiltonians in representations of $SO(4)$. These Hamiltonians can be taken to be proportional to functions of E^4 radius which is $SO(4)$ invariant and these functions bring in additional degree of freedom.

3. The construction of Dirac determinant identified as a vacuum functional can be done also in M^8 picture and the conjecture is that the result is same as in the case of H. In this framework the construction is much simpler due to the flatness of E^4. In particular, the generalized eigen modes of the Dirac operator $D_K(Y^3_l)$ restricted to the X^3_l correspond to a situation in which one has fermion in induced Maxwell field mimicking the neutral part of electro-weak gauge field in H as far as couplings are considered. Induced Kähler field would be same as in H. Eigen modes are localized to regions inside which the Kähler magnetic field is non-vanishing and apart from the fact that the metric is the effective metric defined in terms of canonical momentum densities via the formula $\hat{\Gamma}^\alpha = \partial L_K/\partial h^k_\alpha \Gamma_k$ for effective gamma matrices. This in fact, forces the localization of modes implying that their number is finite so that Dirac determinant is a product over finite number eigenvalues. It is clear that M^8 picture could dramatically simplify the construction of configuration space geometry.

4. The eigenvalue spectra of the transversal parts of D_K operators in M^8 and H should identical. This motivates the question whether it is possible to achieve a complete correspondence between H and M^8 pictures also at the level of spinor fields at X^3 by performing a gauge transformation

eliminating the classical W gauge boson field altogether at X_l^3 and whether this allows to transform the modified Dirac equation in H to that in M^8 when restricted to X_l^3. That something like this might be achieved is supported by the fact that in Coulombic gauge the component of gauge potential in the light-like direction vanishes so that the situation is effectively 2-dimensional and holonomy group is Abelian.

4.4.6 Why $M^8 - H$ duality is useful?

Skeptic could of course argue that $M^8 - H$ duality produces only an inflation of unproven conjectures. There are however strong reasons for $M^8 - H$ duality: both theoretical and physical.

1. The map of $X_l^3 \subset H \rightarrow X_l^3 \subset M^8$ and corresponding map of space-time surfaces would allow to realize number theoretical universality. $M^8 = M^4 \times E^4$ allows linear coordinates as natural coordinates in which one can say what it means that the point of imbedding space is rational/algebraic. The point of $X^4 \subset H$ is algebraic if it is mapped to an algebraic point of M^8 in number theoretic compactification. This of course restricts the symmetry groups to their rational/algebraic variants but this does not have practical meaning. Number theoretical compactication could in fact be motivated by the number theoretical universality.

2. $M^8 - H$ duality could provide much simpler description of preferred extremals of Kähler action since the Kähler form in E^4 has constant components. If the spinor connection in E^4 is combination of the three Kähler forms mimicking neutral part of electro-weak gauge potential, the eigenvalue spectrum for the modified Dirac operator would correspond to that for a fermion in $U(1)$ magnetic field defined by an Abelian magnetic field whereas in $M^4 \times CP_2$ picture $U(2)_{ew}$ magnetic fields would be present.

3. $M^8 - H$ duality provides insights to low energy hadron physics. M^8 description might work when H-description fails. For instance, perturbative QCD which corresponds to H-description fails at low energies whereas M^8 description might become perturbative description at this limit. Strong $SO(4) = SU(2)_L \times SU(2)_R$ invariance is the basic symmetry of the phenomenological low energy hadron models based on conserved vector current hypothesis (CVC) and partially conserved axial current hypothesis (PCAC). Strong $SO(4) = SU(2)_L \times SU(2)_R$ relates closely also to electro-weak gauge group $SU(2)_L \times U(1)$ and this connection is not well understood in QCD description. $M^8 - H$ duality could provide this connection. Strong $SO(4)$ symmetry would emerge as a low energy dual of the color symmetry. Orbital $SO(4)$ would correspond to strong $SU(2)_L \times SU(2)_R$ and by flatness of E^4 spin like $SO(4)$ would correspond to electro-weak group $SU(2)_L \times U(1)_R \subset SO(4)$. Note that the inclusion of coupling to Kähler gauge potential is necessary to achieve respectable spinor structure in CP_2. One could say that the orbital angular momentum in $SO(4)$ corresponds to strong isospin and spin part of angular momentum to the weak isospin.

4.5 $M^8 - H$ duality and low energy hadron physics

The description of $M^8 - H$ at the configuration space level can be applied to gain a view about color confinement and its dual for electro-weak interactions at short distance limit. The basic idea is that $SO(4)$ and $SU(3)$ provide provide dual descriptions of quark color using E^4 and CP_2 partial waves and low energy hadron physics corresponds to a situation in which M^8 picture provides the perturbative approach whereas H picture works at high energies. The basic prediction is that $SO(4)$ should appear as dynamical symmetry group of low energy hadron physics and this is indeed the case.

Consider color confinement at the long length scale limit in terms of $M^8 - H$ duality.

1. At high energy limit only lowest color triplet color partial waves for quarks dominate so that QCD description becomes appropriate whereas very higher color partial waves for quarks and gluons are expected to appear at the confinement limit. Since configuration space degrees of freedom begin to dominate, color confinement limit transcends the descriptive power of QCD.

2. The success of $SO(4)$ sigma model in the description of low lying hadrons would directly relate to the fact that this group labels also the E^4 Hamiltonians in M^8 picture. Strong $SO(4)$ quantum numbers can be identified as orbital counterparts of right and left handed electro-weak isospin

coinciding with strong isospin for lowest quarks. In sigma model pion and sigma boson form the components of E^4 valued vector field or equivalently collection of four E^4 Hamiltonians corresponding to spherical E^4 coordinates. Pion corresponds to S^3 valued unit vector field with charge states of pion identifiable as three Hamiltonians defined by the coordinate components. Sigma is mapped to the Hamiltonian defined by the E^4 radial coordinate. Excited mesons corresponding to more complex Hamiltonians are predicted.

3. The generalization of sigma model would assign to quarks E^4 partial waves belonging to the representations of $SO(4)$. The model would involve also 6 $SO(4)$ gluons and their $SO(4)$ partial waves. At the low energy limit only lowest representations would be be important whereas at higher energies higher partial waves would be excited and the description based on CP_2 partial waves would become more appropriate.

4. The low energy quark model would rely on quarks moving $SO(4)$ color partial waves. Left *resp.* right handed quarks could correspond to $SU(2)_L$ *resp.* $SU(2)_R$ triplets so that spin statistics problem would be solved in the same manner as in the standard quark model.

5. Family replication phenomenon is described in TGD framework the same manner in both cases so that quantum numbers like strangeness and charm are not fundamental. Indeed, p-adic mass calculations allowing fractally scaled up versions of various quarks allow to replace Gell-Mann mass formula with highly successful predictions for hadron masses [20] .

To my opinion these observations are intriguing enough to motivate a concrete attempt to construct low energy hadron physics in terms of $SO(4)$ gauge theory.

4.6 The notion of number theoretical braid

Braids -not necessary number theoretical- provide a realization discretization as a space-time correlate for the finite measurement resolution. The notion of braid was inspired by the idea about quantum TGD as almost topological quantum field theory. Although the original form of this idea has been buried, the notion of braid has survived: in the decomposition of space-time sheets to string world sheets, the ends of strings define representatives for braid strands at light-like 3-surfaces.

The notion of number theoretic universality inspired the much more restrictive notion of number theoretic braid requiring that the points in the intersection of the braid with the partonic 2-surface correspond to rational or at most algebraic points of H in preferred coordinates fixed by symmetry considerations. The challenge has been to find a unique identification of the number theoretic braid or at least of the end points of the braid. The following consideration suggest that the number theoretic braids are not a useful notion in the generic case but make sense and are needed in the intersection of real and p-adic worlds which is in crucial role in TGD based vision about living matter [16] .

It is only the braiding that matters in topological quantum field theories used to classify braids. Hence braid should require only the fixing of the end points of the braids at the intersection of the braid at the light-like boundaries of CDs and the braiding equivalence class of the braid itself. Therefore it is enough is to specify the topology of the braid and the end points of the braid in accordance with the attribute "number theoretic". Of course, the condition that all points of the strand of the number theoretic braid are algebraic is impossible to satisfy.

The situation in which the equations defining X^2 make sense both in real sense and p-adic sense using appropriate algebraic extension of p-adic number field is central in the TGD based vision about living matter [16] . The reason is that in this case the notion of number entanglement theoretic entropy having negative values makes sense and entanglement becomes information carrying. This motivates the identification of life as something in the intersection of real and p-adic worlds. In this situation the identification of the ends of the number theoretic braid as points belonging to the intersection of real and p-adic worlds is natural. These points -call them briefly algebraic points- belong to the algebraic extension of rationals needed to define the algebraic extension of p-adic numbers. This definition however makes sense also when the equations defining the partonic 2-surfaces fail to make sense in both real and p-adic sense. In the generic case the set of points satisfying the conditions is discrete. For instance, according to Fermat's theorem the set of rational points satisfying $X^n+Y^n = Z^n$ reduces to the point $(0,0,0)$ for $n = 3,4,....$ Hence the constraint might be quite enough in the intersection of real and p-adic worlds where the choice of the algebraic extension is unique.

One can however criticize this proposal.

1. One must fix the the number of points of the braid and outside the intersection and the non-uniquencess of the algebraic extension makes the situation problematic. Physical intuition suggests that the points of braid define carriers of quantum numbers assignable to second quantized induced spinor fields so that the total number of fermions antifermions would define the number of braids. In the intersection the highly non-trivial implication is that this number cannot exceed the number of algebraic points.

2. In the generic case one expects that even the smallest deformation of the partonic 2-surface can change the number of algebraic points and also the character of the algebraic extension of rational numbers needed. The restriction to rational points is not expected to help in the generic case. If the notion of number theoretical braid is meant to be practical, must be able to decompose WCW to open sets inside which the numbers of algebraic points of braid at its ends are constant. For real topology this is expected to be impossible and it does not make sense to use p-adic topology for WCW whose points do not allow interpretation as p-adic partonic surfaces.

3. In the intersection of real and p-adic worlds which corresponds to a discrete subset of WCW, the situation is different. Since the coefficients of polynomials involved with the definition of the partonic 2-surface must be rational or at most algebraic, continuous deformations are not possible so that one avoids the problem.

4. This forces to ask the reason why for the number theoretic braids. In the generic case they seem to produce only troubles. In the intersection of real and p-adic worlds they could however allow the construction of the elements of M-matrix describing quantum transitions changing p-adic to real surfaces and vice versa as realizations of intentions and generation of cognitions. In this the case it is natural that only the data from the intersection of the two worlds are used. In [16] I have sketched the idea about number theoretic quantum field theory as a description of intentional action and cognition.

There is also the the problem of fixing the interior points of the braid modulo deformations not affecting the topology of the braid.

1. Infinite number of non-equivalent braidings are possible. Should one allow all possible braidings for a fixed light-like 3-surface and say that their existence is what makes the dynamics essentially three-dimensional even in the topological sense? In this case there would be no problems with the condition that the points at both ends of braid are algebraic.

2. Or should one try to characterize the braiding uniquely for a given partonic 2-surfaces and corresponding 4-D tangent space distributions? The slicing of the space-time sheet by partonic 2-surfaces and string word sheets suggests that the ends of string world sheets could define the braid strands in the generic context when there is no algebraicity condition involved. This could be taken as a very natural manner to fix the topology of braid but leave the freedom to choose the representative for the braid. In the intersection of real and p-adic worlds there is no good reason for the end points of strands in this case to be algebraic at both ends of the string world sheet. One can however start from the braid defined by the end points of string world sheets, restrict the end points to be algebraic at the end with a smaller number of algebraic points and and then perform a topologically non-trivial deformation of the braid so that also the points at the other end are algebraic? Non-trivial deformations need not be possible for all possible choices of algebraic braid points at the other end of braid and different choices of the set of algebraic points would give rise to different braidings. A further constraint is that only the algebraic points at which one has assign fermion or antifermion are used so that the number of braid points is not always maximal.

3. One can also ask whether one should perform the gauge fixing for the strands of the number theoretic braid using algebraic functions making sense both in real and p-adic context. This question does not seem terribly relevant since since it is only the topology of the braid that matters.

4.7 Connection with string model and Equivalence Principle at space-time level

Coset construction allows to generalize Equivalence Principle and understand it at quantum level. This is however not quite enough: a precise understanding of Equivalence Principle is required also at the classical level. Also the mechanism selecting via stationary phase approximation a preferred extremal of Kähler action providing a correlation between quantum numbers of the particle and geometry of the preferred extremals is still poorly understood.

4.7.1 Is stringy action principle coded by the geometry of preferred extremals?

It seems very difficult to deduce Equivalence Principle as an identity of gravitational and inertial masses identified as Noether charges associated with corresponding action principles. Since string model is an excellent theory of quantum gravitation, one can consider a less direct approach in which one tries to deduce a connection between classical TGD and string model and hope that the bridge from string model to General Relativity is easier to build. Number theoretical compactification gives good hopes that this kind of connection exists.

1. Number theoretic compactification implies that the preferred extremals of Kähler action have the property that one can assign to each point of M^4 projection $P_{M^4}(X^4(X^3_l))$ of the preferred extremal $M^2(x)$ identified as the plane of non-physical polarizations and also as the plane in which local massless four-momentum lies.

2. If the distribution of the planes $M^2(x)$ is integrable, one can slice $P_{M^4}(X^4(X^3_l))$ to string world-sheets. The intersection of string world sheets with $X^3 \subset \delta M^4_\pm \times CP_2$ corresponds to a light-like curve having tangent in local tangent space $M^2(x)$ at light-cone boundary. This is the first candidate for the definition of number theoretic braid. Second definition assumes M^2 to be fixed at δCD: in this case the slicing is parameterized by the sphere S^2 defined by the light rays of $\delta M^4_\pm$.

3. One can assign to the string world sheet -call it Y^2 - the standard area action

$$S_G(Y^2) = \int_{Y^2} T\sqrt{g_2}d^2y \ , \tag{4.1}$$

   where g_2 is either the induced metric or only its M^4 part. The latter option looks more natural since M^4 projection is considered. T is string tension.

4. The naivest guess would be $T = 1/\hbar G$ apart from some numerical constant but one must be very cautious here since $T = 1/L_p^2$ apart from a numerical constant is also a good candidate if one accepts the basic argument identifying G in terms of p-adic length L_p and Kähler action for two pieces of CP_2 type vacuum extremals representing propagating graviton. The formula reads $G = L_p^2 exp(-2aS_K(CP_2))$, $a \leq 1$ [2, 10] . The interaction strength which would be L_p^2 without the presence of CP_2 type vacuum extremals is reduced by the exponential factor coming from the exponent of Kähler function of configuration space.

5. One would have string model in either $CD \times CP_2$ or $CD \subset M^4$ with the constraint that stringy world sheet belongs to $X^4(X^3_l)$. For the extremals of $S_G(Y^2)$ gravitational four-momentum defined as Noether charge is conserved. The extremal property of string world sheet need not however be consistent with the preferred extremal property. This constraint might bring in coupling of gravitons to matter. The natural guess is that graviton corresponds to a string connecting wormhole contacts. The strings could also represent formation of gravitational bound states when they connect wormhole contacts separated by a large distance. The energy of the string is roughly $E \sim \hbar TL$ and for $T = 1/\hbar G$ gives $E \sim L/G$. Macroscopic strings are not allowed except as models of black holes. The identification $T \sim 1/L_p^2$ gives $E \sim \hbar L/L_p^2$, which does not favor long strings for large values of $\hbar$. The identification $G_p = L_p^2/\hbar_0$ gives $T = 1/\hbar G_p$ and $E \sim \hbar_0 L/L_p^2$, which makes sense and allows strings with length not much longer than p-adic length scale. Quantization - that is the presence of configuration space degrees of freedom-

would bring in massless gravitons as deformations of string whereas strings would carry the gravitational mass.

6. The exponent $exp(iS_G)$ can appear as a phase factor in the definition of quantum states for preferred extremals. S_G is not however enough. One can assign also to the points of number theoretic braid action describing the interaction of a point like current Qdx^μ/ds with induced gauge potentials A_μ. The corresponding contribution to the action is

$$S_{braid} = \int_{braid} iTr(Q\frac{dx^\mu}{ds}A_\mu)dx \ . \tag{4.2}$$

In stationary phase approximation subject to the additional constraint that a preferred extremal of Kähler action is in question one obtains the desired correlation between the geometry of preferred extremal and the quantum numbers of elementary particle. This interaction term carries information only about the charges of elementary particle. It is quite possible that the interaction term is more complex: for instance, it could contain spin dependent terms (Stern-Gerlach experiment).

7. The constraint coming from preferred extremal property of Kähler action can be expressed in terms of Lagrange multipliers

$$S_c = \int_{Y^2} \lambda^k D_\alpha(\frac{\partial L_K}{\partial_\alpha h^k})\sqrt{g_2}d^2y \ . \tag{4.3}$$

8. The action exponential reads as

$$exp(iS_G + S_{braid} + S_c) \ . \tag{4.4}$$

The resulting field equations couple stringy M^4 degrees of freedom to the second variation of Kähler action with respect to M^4 coordinates and involve third derivatives of M^4 coordinates at the right hand side. If the second variation of Kähler action with respect to M^4 coordinates vanishes, free string results. This is trivially the case if a vacuum extremal of Kähler action is in question.

9. An interesting question is whether the preferred extremal property boils down to the condition that the second variation of Kähler action with respect to M^4 coordinates or actually all coordinates vanishes so that gravitonic string is free. As a matter fact, the stronger condition is required that the Noether currents associated with the modified Dirac action are conserved. The physical interpretation would be in terms of quantum criticality which is the basic conjecture about the dynamics of quantum TGD. This is clear from the fact that in 1-D system criticality means that the potential $V(x) = ax+bx^2+..$ has $b = 0$. In field theory criticality corresponds to the vanishing of the term $m^2\phi^2/2$ so that massless situation corresponds to massless theory and criticality and long range correlations. For more than one dynamical variable there is a hierarchy of criticalities corresponding to the gradual reduction of the rank of the matrix of the matrix defined by the second derivatives of $V(x)$ and this gives rise to a classification of criticalities. Maximum criticality would correspond to the total vanishing of this matrix. In infinite-D case this hierarchy is infinite.

4.7.2 What does the equality of gravitational and inertial masses mean?

Consider next the question in what form Equivalence Principle could be realized in this framework.

1. Coset construction inspires the conjecture that gravitational and inertial four-momenta are identical. Also some milder form of it would make sense. What is clear is that the construction of preferred extremal involving the distribution of $M^2(x)$ implies that conserved four-momentum

associated with Kähler action can be expressed formally as stringy four-momentum. The integral of the conserved inertial momentum current over X^3 indeed reduces to an integral over the curve defining string as one integrates over other two degrees of freedom. It would not be surprising if a stringy expression for four-momentum would result but with string tension depending on the point of string and possibly also on the component of four-momentum. If the dependence of string tension on the point of string and on the choice of the stringy world sheet is slow, the interpretation could be in terms of coupling constant evolution associated with the stringy coordinates. An alternative interpretation is that string tension corresponds to a scalar field. A quite reasonable option is that for given X_l^3 T defines a scalar field and that the observed T corresponds to the average value of T over deformations of X_l^3.

2. The minimum option is that Kähler mass is equal to the sum gravitational masses assignable to strings connecting points of wormhole throat or two different wormhole throats. This hypothesis makes sense even for wormhole contacts having size of order Planck length.

3. The condition that gravitational mass equals to the inertial mass (rest energy) assigned to Kähler action is the most obvious condition that one can imagine. The breaking of Poincare invariance to Lorentz invariance with respect to the tip of CD supports this form of Equivalence Principle. This would predict the value of the ratio of the parameter R^2T and p-adic length scale hypothesis would allow only discrete values for this parameter. $p \simeq 2^k$ following from the quantization of the temporal distance $T(n)$ between the tips of CD as $T(n) = 2^nT_0$ would suggest string tension $T_n = 2^nR^2$ apart from a numerical factor. $G_p \propto 2^nR^2/\hbar_0$ would emerge as a prediction of the theory. G can be seen either as a prediction or RG invariant input parameter fixed by quantum criticality. The arguments related to p-adic coupling constant evolution suggest $R^2/\hbar_0G = 3 \times 2^{23}$ [2, 10] .

4. The scalar field property of string tension should be consistent with the vacuum degeneracy of Kähler action. For instance, for the vacuum extremals of Kähler action stringy action is non-vanishing. The simplest possibility is that one includes the integral of the scalar $J^{\mu\nu}J_{\mu\nu}$ over the degrees transversal to M^2 to the stringy action so that string tension vanishes for vacuum extremals. This would be nothing but dimensional reduction of 4-D theory to a 2-D theory using the slicing of $X^4(X_l^3)$ to partonic 2-surfaces and stringy word sheets. For cosmic strings Kähler action reduces to stringy action with string tension $T \propto 1/g_K^2R^2$ apart from a numerical constant. If one wants consistency with $T \propto 1/L_p^2$, one must have $T \propto 1/g_K^2 2^nR^2$ for the cosmic strings deformed to Kähler magnetic flux tubes. This looks rather plausible if the thickness of deformed string in M^4 degrees of freedom is given by p-adic length scale.

5 An attempt to understand preferred extremals of Kähler action

There are pressing motivations for understanding the preferred extremals of Kähler action. For instance, the conformal invariance of string models naturally generalizes to 4-D invariance defined by quantum Yangian of quantum affine algebra (Kac-Moody type algebra) characterized by two complex coordinates and therefore explaining naturally the effective 2-dimensionality [31]. The problem is however how to assign a complex coordinate with the string world sheet having Minkowskian signature of metric. One can hope that the understanding of preferred extremals could allow to identify two preferred complex coordinates whose existence is also suggested by number theoretical vision giving preferred role for the rational points of partonic 2-surfaces in preferred coordinates. The best one could hope is a general solution of field equations in accordance with the hints that TGD is integrable quantum theory.

A lot is is known about properties of preferred extremals and just by trying to integrate all this understanding, one might gain new visions. The problem is that all these arguments are heuristic and rely heavily on physical intuition. The following considerations relate to the space-time regions having Minkowskian signature of the induced metric. The attempt to generalize the construction also to Euclidian regions could be very rewarding. Only a humble attempt to combine various ideas to a more coherent picture is in question.

The core observations and visions are following.

1. Hamilton-Jacobi coordinates for M^4 (discussed in this chapter) define natural preferred coordinates for Minkowskian space-time sheet and might allow to identify string world sheets for X^4 as those for M^4. Hamilton-Jacobi coordinates consist of light-like coordinate m and its dual defining local 2-plane $M^2 \subset M^4$ and complex transversal complex coordinates $(w, \overline{w})$ for a plane E^2_x orthogonal to M^2_x at each point of M^4. Clearly, hyper-complex analyticity and complex analyticity are in question.

2. Space-time sheets allow a slicing by string world sheets (partonic 2-surfaces) labelled by partonic 2-surfaces (string world sheets).

3. The quaternionic planes of octonion space containing preferred hyper-complex plane are labelled by CP_2, which might be called CP_2^{mod} [27]. The identification $CP_2 = CP_2^{mod}$ motivates the notion of $M^8 - -M^4 \times CP_2$ duality [7]. It also inspires a concrete solution ansatz assuming the equivalence of two different identifications of the quaternionic tangent space of the space-time sheet and implying that string world sheets can be regarded as strings in the 6-D coset space $G_2/SU(3)$. The group G_2 of octonion automorphisms has already earlier appeared in TGD framework.

4. The duality between partonic 2-surfaces and string world sheets in turn suggests that the $CP_2 = CP_2^{mod}$ conditions reduce to string model for partonic 2-surfaces in $CP_2 = SU(3)/U(2)$. String model in both cases could mean just hypercomplex/complex analyticity for the coordinates of the coset space as functions of hyper-complex/complex coordinate of string world sheet/partonic 2-surface.

The considerations of this section lead to a revival of an old very ambitious and very romantic number theoretic idea.

1. To begin with express octonions in the form $o = q_1 + Iq_2$, where q_i is quaternion and I is an octonionic imaginary unit in the complement of fixed a quaternionic sub-space of octonions. Map preferred coordinates of $H = M^4 \times CP_2$ to octonionic coordinate, form an arbitrary octonion analytic function having expansion with real Taylor or Laurent coefficients to avoid problems due to non-commutativity and non-associativity. Map the outcome to a point of H to get a map $H \rightarrow H$. This procedure is nothing but a generalization of Wick rotation to get an 8-D generalization of analytic map.

2. Identify the preferred extremals of Kähler action as surfaces obtained by requiring the vanishing of the imaginary part of an octonion analytic function. Partonic 2-surfaces and string world sheets would correspond to commutative sub-manifolds of the space-time surface and of imbedding space and would emerge naturally. The ends of braid strands at partonic 2-surface would naturally correspond to the poles of the octonion analytic functions. This would mean a huge generalization of conformal invariance of string models to octonionic conformal invariance and an exact solution of the field equations of TGD and presumably of quantum TGD itself.

5.1 Basic ideas about preferred extremals

5.1.1 The slicing of the space-time sheet by partonic 2-surfaces and string world sheets

The basic vision is that space-time sheets are sliced by partonic 2-surfaces and string world sheets. The challenge is to formulate this more precisely at the level of the preferred extremals of Kähler action.

1. Almost topological QFT property means that the Kähler action reduces to Chern-Simons terms assignable to 3-surfaces. This is guaranteed by the vanishing of the Coulomb term in the action density implied automatically if conserved Kähler current is proportional to the instanton current with proportionality coefficient some scalar function.

2. The field equations reduce to the conservation of isometry currents. An attractive ansatz is that the flow lines of these currents define global coordinates. This means that these currents are Beltrami flows [3] so that corresponding 1-forms J satisfy the condition $J \wedge dJ = 0$. These conditions are satisfied if

$$J = \Phi \nabla \Psi$$

hold true for conserved currents. From this one obtains that Ψ defines global coordinate varying along flow lines of J.

3. A possible interpretation is in terms of local polarization and momentum directions defined by the scalar functions involved and natural additional conditions are that the gradients of Ψ and Φ are orthogonal:

$$\nabla \Phi \cdot \nabla \Psi = 0 \ ,$$

and that the Ψ satisfies massless d'Alembert equation

$$\nabla^2 \Psi = 0$$

as a consequence of current conservation. If Ψ defines a light-like vector field - in other words

$$\nabla \Psi \cdot \nabla \Psi = 0 \ ,$$

the light-like dual of Φ -call it Φ_c- defines a light-like like coordinate and Φ and Φ_c defines a light-like plane at each point of space-time sheet.

If also Φ satisfies d'Alembert equation

$$\nabla^2 \Phi = 0 \ ,$$

also the current

$$K = \Psi \nabla \Phi$$

is conserved and its flow lines define a global coordinate in the polarization plane orthogonal to time-lik plane defined by local light-like momentum direction.

If Φ allows a contination to an analytic function of the transversal complex coordinate, one obtains a coordinatization of spacetime surface by Ψ and its dual (defining hyper-complex coordinate) and $w, \overline{w}$. Complex analyticity and its hyper-complex variant would allow to provide space-time surface with four coordinates very much analogous with Hamilton-Jacobi coordinates of M^4.

This would mean a decomposition of the tangent space of space-time surface to orthogonal planes defined by light-like momentum and plane orthogonal to it. If the flow lines of J defined Beltrami flow it seems that the distribution of momentum planes is integrable.

4. General arguments suggest that the space-time sheets allow a slicing by string world sheets parametrized by partonic 2-surfaces or vice versa. This would mean a intimate connection with the mathematics of string models. The two complex coordinates assignable to the Yangian of affine algebra would naturally relate to string world sheets and partonic 2-surfaces and the highly non-trivial challenge is to identify them appropriately.

5.1.2 Hamilton-Jacobi coordinates for M^4

The earlier attempts to construct preferred extremals [3] led to the realization that so called Hamilton-Jacobi coordinates (m, w) for M^4 define its slicing by string world sheets parametrized by partonic 2-surfaces. m would be pair of light-like conjugate coordinates associated with an integrable distribution of planes M^2 and w would define a complex coordinate for the integrable distribution of 2-planes E^2 orthogonal to M^2. There is a great temptation to assume that these coordinates define prefered coorinates for M^4.

1. The slicing is very much analogous to that for space-time sheets and the natural question is how these slicings relate. What is of special interest is that the momentum plane M^2 can be defined by massless momentum. The scaling of this vector does not matter so that these planes are labelled by points z of sphere S^2 telling the direction of the line $M^2 \cap E^3$, when one assigns rest frame and therefore S^2 with the preferred time coordinate defined by the line connecting the tips of CD. This direction vector can be mapped to a twistor consisting of a spinor and its conjugate. The complex scalings of the twistor $(u, \overline{u}) \to \lambda u, \overline{u}/\lambda)$ define the same plane. Projective twistor like entities defining CP_1 having only one complex component instead of three are in question. This complex number defines with certain prerequisites a local coordinate for space-time sheet and together with the complex coordinate of E^2 could serve as a pair of complex coordinates (z, w) for space-time sheet. This brings strongly in mind the two complex coordinates appearing in the expansion of the generators of quantum Yangian of quantum affine algebra [31].

2. The coordinate Ψ appearing in Beltrami flow defines the light-like vector field defining M^2 distribution. Its hyper-complex conjugate would define Ψ_c and conjugate light-like direction. An attractive possibility is that Φ allows analytic continuation to a holomorphic function of w. In this manner one would have four coordinates for M^4 also for space-time sheet.

3. The general vision is that at each point of space-time surface one can decompose the tangent space to $M^2(x) \subset M^4 = M^2_x \times E^2_x$ representing momentum plane and polarization plane $E^2 \subset E^2_x \times T(CP_2)$. The moduli space of planes $E^2 \subset E^6$ is 8-dimensional and parametrized by $SO(6)/SO(2) \times SO(4)$ for a given E^2_x. How can one achieve this selection and what conditions it must satisfy? Certainly the choice must be integrable but this is not the only condition.

5.1.3 Space-time surfaces as quaternionic surfaces

The idea that number theory determines classical dynamics in terms of associativity condition means that space-time surfaces are in some sense quaternionic surfaces of an octonionic space-time. It took several trials before the recent form of this hypothesis was achieved.

1. Octonionic structure is defined in terms of the octonionic representaton of gamma matrices of the imbedding space existing only in dimension $D = 8$ since octonion units are in one-one correspondence with tangent vectors of the tangent space. Octonionic real unit corresponds to a preferred time axes (and rest frame) identified naturally as that connecting the tips of CD. What modified gamma matrices mean depends on variational principle for space-time surface. For volume action one would obtain induced gamma matrices. For Kähler action one obtains something different. In particular, the modified gamma matrices do not define vector basis identical with tangent vector basis of space-time surface.

2. Quaternionicity means that the modified gamma matrices defined as contractions of gamma matrices of H with canonical momentum densities for Kähler action span quaternionic sub-space of the octonionic tangent space [11]. A further condition is that each quaternionic space defined in this manner contains a preferred hyper-complex subspace of octonions.

3. The sub-space defined by the modified gamma matrices does not co-incide with the tangent space of space-time surface in general so that the interpretation of this condition is far from obvious. The canonical momentum densities need not define four independent vectors at given point. For instance, for massless extremals these densities are proportional to light-like vector so that the situation is degenerate and the space in question reduces to 2-D hyper-complex sub-space since light-like vector defines plane M^2.

The obvious questions are following.

1. Does the analog of tangent space defined by the octonionic modified gammas contain the local tangent space $M^2 \subset M^4$ for preferred extremals? For massless extremals [3] this condition would be true. The orthogonal decomposition $T(X^4) = M^2 \oplus_\perp E^2$ can be defined at each point if this is true. For massless extremals also the functions Ψ and Φ can be identified.

2. One should answer also the following delicate question. Can M^2 really depend on point x of space-time? CP_2 as a moduli space of quaternionic planes emerges naturally if M^2 is *same* everywhere. It however seems that one should allow an integrable distribution of M^2_x such that M^2_x is same for all points of a given partonic 2-surface.

   How could one speak about fixed CP_2 (the imbedding space) at the entire space-time sheet even when M^2_x varies?

   (a) Note first that G_2 defines the Lie group of octonionic automorphisms and G_2 action is needed to change the preferred hyper-octonionic sub-space. Various $SU(3)$ subgroups of G_2 are related by G_2 automorphism. Clearly, one must assign to each point of a string world sheet in the slicing parameterizing the partonic 2-surfaces an element of G_2. One would have Minkowskian string model with G_2 as a target space. As a matter fact, this string model is defined in the target space $G_2/SU(3)$ having dimension $D = 6$ since $SU(3)$ automorphisms leave given $SU(3)$ invariant.

   (b) This would allow to identify at each point of the string world sheet standard quaternionic basis - say in terms of complexified basis vectors consisting of two hyper-complex units and octonionic unit q_1 with "color isospin" $I_3 = 1/2$ and "color hypercharge" $Y = -1/3$ and its conjugate $\overline{q}_1$ with opposite color isospin and hypercharge.

   (c) The CP_2 point assigned with the quaternionic basis would correspond to the $SU(3)$ rotation needed to rotate the standard basis to this basis and would actually correspond to the first row of $SU(3)$ rotation matrix. Hyper-complex analyticity is the basic property of the solutions of the field equations representing Minkowskian string world sheets. Also now the same assumption is highly natural. In the case of string models in Minkowski space, the reduction of the induced metric to standard form implies Virasoro conditions and similar conditions are expected also now. There is no need to introduce action principle -just the hyper-complex analycitity is enough-since Kähler action already defines it.

3. The WZW model inspired approach to the situation would be following. The parametrization corresponds to a map $g : X^2 \rightarrow G_2$ for which g defines a flat G_2 connection at string world sheet. WZW type action would give rise to this kind of situation. The transition $G_2 \rightarrow G_2/SU(3)$ would require that one gauges $SU(3)$ degrees of freedom by bringing in $SU(3)$ connection. Similar procedure for $CP_2 = SU(3)/U(2)$ would bring in $SU(3)$ valued chiral field and $U(2)$ gauge field. Instead of introducing these connections one can simply introduce $G_2/SU(3)$ and $SU(3)/U(2)$ valued chiral fields. What this observation suggests that this ansatz indeed predicts gluons and electroweak gauge bosons assignable to string like objects so that the mathematical picture would be consistent with physical intuition.

5.1.4 The two interpretations of CP_2

An old observation very relevant for what I have called M^8-H duality [7] is that the moduli space of quaternionic sub-spaces of octonionic space (identifiable as M^8) containing preferred hyper-complex plane is CP_2. Or equivalently, the space of two planes whose addition extends hyper-complex plane to some quaternionic subspace can be parametrized by CP_2. This CP_2 can be called it CP_2^{mod} to avoid confusion. In the recent case this would mean that the space $E^2(x) \subset E^2_x \times T(CP_2)$ is represented by a point of CP_2^{mod}. On the other hand, the imbedding of space-time surface to H defines a point of "real" CP_2. This gives two different CP_2s.

1. The highly suggestive idea is that the identification $CP_2^{mod} = CP_2$ (apart from isometry) is crucial for the construction of preferred extremals. Indeed, the projection of the space-time point to CP_2 would fix the local polarization plane completely. This condition for $E^2(x)$ would be purely local and depend on the values of CP_2 coordinates only. Second condition for $E^2(x)$ would involve the gradients of imbedding space coordinates including those of CP_2 coordinates.

2. The conditions that the planes M^2_x form an integrable distribution at space-like level and that M^2_x is determined by the modified gamma matrices. The integrability of this distribution for M^4 could imply the integrability for X^2. X^4 would differ from M^4 only by a deformation in degrees of freedom transversal to the string world sheets defined by the distribution of M^2s.

Does this mean that one can begin from vacuum extremal with constant values of CP_2 coordinates and makes them non-constant but allows to depend only on transversal degrees of freedom? This condition is too strong even for simplest massless extremals for which CP_2 coordinates depend on transversal coorinates defined by $\epsilon \cdot m$ and $\epsilon \cdot k$. One could however allow dependence of CP_2 coordinates on light-like M^4 coordinate since the modification of the induced metric is light-like so that light-like coordinate remains light-like coordinate in this modification of the metric.

Therefore, if one generalizes directly what is known about massless extremals, the most general dependence of CP_2 points on the light-like coordinates assignable to the distribution of M^2_x would be dependence on either of the light-like coordinates of Hamilton-Jacobi coordinates but not both.

5.2 What could be the construction recipe for the preferred extremals assuming $CP_2 = CP_2^{mod}$ identification?

The crucial condition is that the planes $E^2(x)$ determined by the point of $CP_2 = CP_2^{mod}$ identification and by the tangent space of $E^2_x \times CP_2$ are same. The challenge is to transform this condition to an explicit form. $CP_2 = CP_2^{mod}$ identification should be general coordinate invariant. This requires that also the representation of E^2 as (e^2, e^3) plane is general coordinate invariant suggesting that the use of preferred CP_2 coordinates -presumably complex Eguchi-Hanson coordinates- could make life easy. Preferred coordinates are also suggested by number theoretical vision. A careful consideration of the situation would be required.

The modified gamma matrices define a quaternionic sub-space analogous to tangent space of X^4 but not in general identical with the tangent space: this would be the case only if the action were 4-volume. I will use the notation $T^m_x(X^4)$ about the modified tangent space and call the vectors of $T^m_x(X^4)$ modified tangent vectors. I hope that this would not cause confusion.

5.2.1 $CP_2 = CP_2^{mod}$ condition

Quaternionic property of the counterpart of $T^m_x(X^4)$ allows an explicit formulation using the tangent vectors of $T^m_x(X^4)$.

1. The unit vector pair (e_2, e_3) should correspond to a unique tangent vector of H defined by the coordinate differentials dh^k in some natural coordinates used. Complex Eguchi-Hanson coordinates [1] are a natural candidate for CP_2 and require complexified octonionic imaginary units. If octonionic units correspond to the tangent vector basis of H uniquely, this is possible.

2. The pair (e_2, e_3) as also its complexification $(q_1 = e_2 + ie_3, \overline{q}_1 = e_2 - ie_3)$ is expressible as a linear combination of octonionic units $I_2, ...I_7$ should be mapped to a point of $CP_2^{mod} = CP_2$ in canonical manner. This mapping is what should be expressed explicitly. One should express given (e_2, e_3) in terms of $SU(3)$ rotation applied to a standard vector. After that one should define the corresponding CP_2 point by the bundle projection $SU(3) \rightarrow CP_2$.

3. The tangent vector pair

$$(\partial_w h^k, \partial_{\overline{w}} h^k)$$

defines second representation of the tangent space of $E^2(x)$. This pair should be equivalent with the pair $(q_1, \overline{q}_1)$. Here one must be however very cautious with the choice of coordinates. If the choice of w is unique apart from constant the gradients should be unique. One can use also real coordinates (x, y) instead of $(w = x + iy, \overline{w} = x - iy)$ and the pair (e_2, e_3). One can project the tangent vector pair to the standard vielbein basis which must correspond to the octonioni basis

$$(\partial_x h^k, \partial_y h^k) \rightarrow (\partial_x h^k e^A_k e_A, \partial_y h^k e^A_k) e_A) \leftrightarrow (e_2, e_3) \quad ,$$

where the e_A denote the octonion units in 1-1 correspondence with vielbein vectors. This expression can be compared to the expression of (e_2, e_3) derived from the knowledge of CP_2 projection.

5.2.2 Formulation of quaternionicity condition in terms of octonionic structure constants

One can consider also a formulation of the quaternionic tangent planes in terms of (e_2, e_3) expressed in terms of octonionic units deducible from the condition that unit vectors obey quaternionic algebra. The expressions for octonionic *resp.* quaternionic structure constants can be found at [4] *resp.* [5].

1. The ansatz is

$$\begin{aligned} \{E_k\} &= \{1, I_1, E_2, E_3\} \ , \\ E_2 &= E_{2k}e^k \equiv \sum_{k=2}^{7} E_{2k}e^k \ \ , \ \ E_3 = E_{3k}e^k \equiv \sum_{k=2}^{7} E_{3k}e^k \ \ , \\ |E_2| &= 1 \ \ , \ \ |E_3| = 1 \ . \end{aligned} \tag{5.1}$$

2. The multiplication table for octonionic units expressible in terms of octonionic triangle [4] gives

$$f^{1kl}E_{2k} = E_{3l} \ \ , \ \ f^{1kl}E_{3k} = -E_{2l} \ \ , \ \ f^{klr}E_{2k}E_{3l} = \delta_1^r \ . \tag{5.2}$$

   Here the indices are raised by unit metric so that there is no difference between lower and upper indices. Summation convention is assumed. Also the contribution of the real unit is present in the structure constants of third equation but this contribution must vanish.

3. The conditions are linear and quadratic in the coefficients E_{2k} and E_{3k} and are expected to allow an explicit solution. The first two conditions define homogenous equations which must allow solution. The coefficient matrix acting on (E_2, E_3) is of the form

$$\left(\begin{array}{cc} f_1 & 1 \\ -1 & f_1 \end{array} \right) \ ,$$

   where 1 denotes unit matrix. The vanishing of the determinant of this matrix should be due to the highly symmetric properties of the structure constants. In fact the equations can be written as eigen conditions

$$f_1 \circ (E_2 \pm iE_3) = \mp i(E_2 \pm iE_3) \ \ ,$$

   and one can say that the structure constants are eigenstates of the hermitian operator defined by I_1 analogous to color hyper charge. Both values of color hyper charged are obtained.

5.2.3 Explicit expression for the $CP_2 = CP_2^{mod}$ conditions

The symmetry under $SU(3)$ allows to construct the solutions of the above equations directly.

1. One can introduce complexified basis of octonion units transforming like $(1, 1, 3, \overline{3})$ under SU(3). Note the analogy of triplet with color triplet of quarks. One can write complexified basis as $(1, e_1, (q_1, q_2, q_3), (\overline{q}_1\overline{q}_2, \overline{q}_3))$. The expressions for complexified basis elements are

$$(q_1, q_2, q_3) = \frac{1}{\sqrt{2}}(e_2 + ie_3, e_4 + ie_5, e_6 + ie_7) \ \ .$$

   These options can be seen to be possible by studying octonionic triangle in which all lines containing 3 units defined associative triple: any pair of octonion units at this kind o fline can be used to form pair of complexified unit and its conjugate. In the tangent space of $M^4 \times CP_2$ the basis vectors q_1, and q_2 are mixtures of E_x^2 and CP_2 tangent vectors. q_3 involves only CP_2 tangent vectors and there is a temptation to interpret it as the analog of the quark having no color isospin.

2. The quaternionic basis is real and must transform like $(1, 1, q_1, \overline{q}_1)$, where q_1 is any quark in the triplet and $\overline{q}_1$ its conjugate in antitriplet. Having fixed some basis one can perform SU(3) rotations to get a new basis. The action of the rotation is by 3×3 special unitary matrix. The over all phases of its rows do not matter since they induce only a rotation in (e_2, e_3) plane not affecting the plane itself. The action of $SU(3)$ on q_1 is simply the action of its first row on (q_1, q_2, q_3) triplet:

$$\begin{aligned} q_1 &\rightarrow (Uq)_1 = U_{11}q_1 + U_{12}q_2 + U_{13}q_3 \equiv z_1q_1 + z_2q_2 + z_3q_3 \\ &= z_1(e_2 + ie_3) + z_2(e_4 + ie_5) + z_3(e_6 + ie_7) \ . \end{aligned} \tag{5.3}$$

The triplets (z_1, z_2, z_3) defining a complex unit vector and point of S^5. Since overall phase does not matter a point of CP_2 is in question. The new real octonion units are given by the formulas

$$\begin{aligned} e_2 &\rightarrow Re(z_1)e_2 + Re(z_2)e_4 + Re(z_3)e_6 - Im(z_1)e_3 - Im(z_2)e_5 - Im(z_3)e_7 \ , \\ e_3 &\rightarrow Im(z_1)e_2 + Im(z_2)e_4 + Im(z_3)e_6 + Re(z_1)e_3 + Re(z_2)e_5 + Re(z_3)e_7 \ . \end{aligned} \tag{5.4}$$

For instance the CP_2 coordinates corresponding to the coordinate patch (z_1, z_2, z_3) with $z_3 \neq 0$ are obtained as $(\xi_1, \xi_2) = (z_1/z_3, z_2/z_3)$.

Using these expressions the equations expressing the conjecture $CP_2 = CP_2^{mod}$ equivalence can be expressed explicitly as first order differential equations. The conditions state the equivalence

$$(e_2, e_3) \leftrightarrow (\partial_x h^k e_k^A e_A, \partial_y h^k e_k^A e_A) \ , \tag{5.5}$$

where e_A denote octonion units. The comparison of two pairs of vectors requires normalization of the tangent vectors on the right hand side to unit vectors so that one takes unit vector in the direction of the tangent vector. After this the vectors can be equated. This allows to expresses the contractions of the partial derivatives with vielbein vectors with the 6 components of e_2 and e_3. Each condition gives 6+6 first order partial differential equations which are non-linear by the presence of the overal normalization factor for the right hand side. The equations are invariant under scalings of (x, y). The very special form of these equations suggests that some symmetry is involved.

It must be emphasized that these equations make sense only in preferred coordinates: ordinary Minkowski coordinates and Hamiltonin-Jacobi coordinates for M^4 and Eguchi-Hanson complex coordinates in which $SU(2) \times U(1)$ is represented linearly for CP_2. These coordinates are preferred because they carry deep physical meaning.

5.2.4 Does TGD boil down to two string models?

It is good to look what have we obtained. Besides Hamilton-Jacobi conditions, and $CP_2 = CP_2^{mod}$ conditions one has what one might call string model with 6-dimensional $G_2/SU(3)$ as targent space. The orbit of string in $G_2/SU(3)$ allows to deduce the G_2 rotation identifiable as a point of $G_2/SU(3)$ defining what one means with standard quaternionic plane at given point of string world sheet. The hypothesis is that hyper-complex analyticity solves these equations.

The conjectured electric-magnetic duality implies duality between string world sheet and partonic 2-surfaces central for the proposed mathematical applications of TGD [13, 14, 25, 32]. This duality suggests that the solutions to the $CP_2 = CP_2^{mod}$ conditions could reduce to holomorphy with respect to the coordinate w for partonic 2-surface plus the analogs of Virasoro conditions. The dependence on light-like coordinate would appear as a parametric dependence.

If this were the case, TGD would reduce at least partially to what might be regaded as dual string models in $G_2/SU(3)$ and $SU(3)/U(2)$ and also to string model in M^4 and X^4! In the previous arguments one ends up to string models in moduli spaces of string world sheets and partonic 2-surfaces. TGD seems to yield an inflation of string models! This not actually surprising since the slicing of space-time sheets by string world sheets and partonic 2-surfaces implies automatically various kinds of maps having interpretation in terms of string orbits.

5.3 Could octonion analyticity solve the field equations?

The interesting question is what happens in the space-time regions with Euclidian signature of induced metric. In this case it is not possible to introduce light-like plane at each point of the space-time sheet. Nothing however prevents from applying the above described procedure to construct conserved currents whose flow lines define global coordinates. In both cases analytic continuation allows to extend the coordinates to complex coordinates. Therefore one would have two complex functions satisfying Laplace equation and having orthogonal gradients.

1. When CP_2 projection is 4-dimensional, there is strong temptation to assume that these functions could be reduced to complex CP_2 coordinates analogous to the Hamilton-Jacobi coordinates for M^4. Complex Eguchi-Hanson coordinates transforming linearly under $U(2) \subset SU(3)$ define the simplest candidates in this respect. Laplace-equations are satisfied utomatically since holomorphic functions are in question. The gradients are also orthogonal automatically since the metric is Kähler metric. Note however that one could argue that in innner product the conjugate of the function appears. Any holomorphic map defines new coordinates of this kind. Note that the maps need not be globally holomorphic since CP_2 projection of space-time sheet need not cover the entire CP_2.

2. For string like objects $X^4 = X^2 \times Y^2 \subset M^4 \times CP_2$ with Minkowskian signature of the metric the coordinate pair would be hyper-complex coordinate in M^4 and complex coordinate in CP_2. If X^2 has Euclidian signature of induced metric the coordinate in question would be complex coordinate. The proposal in the case of CP_2 allows all holomorphic functions of the complex coordinates.

There is an objection against this construction. There should be a symmetry between M^4 and CP_2 but this is not the case. Therefore this picture cannot be quite correct.

Could the construction of new preferred coordinates by holomorphic maps generalize as electic-magnetic duality suggests? One can imagine several options, which bring in mind old ideas that what I have christened as "romantic stuff" [27].

1. Should one generalize the holomorphic map to a quaternion analytic map with real Taylor coefficients so that non-commutativity would not produce problems. One would map first M^4 coordinates to quaternions, map these coordinates to new ones by quaternion analytic map defined by a Taylor or even Laurnte expansion with real coefficients, and then map the resulting quaternion valued coordinate back to hyper-quaternion defining four coordinates as fuctions in M^4. This procedure would be very much analogous to Wick rotation used in quantum field theories. Similar quaternion analytic map be applied also in CP_2 degrees of freedom followed by the map of the quaternion to two complex numbers. This would give additional constraints on the map. This option could be seen as a quaternionic generalization of conformal invariance.

   The problem is that one decouples M^4 and CP_2 degrees of freedom completely. These degrees are however coupled in the proposed construction since the $E^2(x)$ corresponds to subspace of $E^2_x \times T(CP_2)$. Something goes still wrong.

2. This motivates to imagine even more ambitious and even more romantic option realizing the original idea about octonionic generalization of conformal invariance. Assume linear $M^4 \times CP_2$ coordinates (Eguchi-Hanson coordinates transforming linearly under $U(2)$ in the case of CP_2). Map these to octonionic coordinate h. Map the octonionic coordinate to itself by an octonionic analytic map defined by Taylor or even Laurent series with real coefficients so that non-commutativity and non-associativity do not cause troubles. Map the resulting octonion valued coordinates back to ordinary H-coordinates and expressible as functions of original coordinates.

   It must be emphasized that this would be nothing but a generalization of Wick rotation and its inverse used routinely in quantum field theories in order to define loop integrals.

5.3.1 Could octonion real-analyticity make sense?

Suppose that one -for a fleeting moment- takes octonionic analyticity seriously. For space-time surfaces themselves one should have in some sense quaternionic variant of conformal invariance. What does this mean?

1. Could one regard space-time surfaces analogous to the curves at which the imaginary part of analytic function of complex argument vanishes so that complex analyticity reduces to real analyticity. One can indeed divide octonion to quaternion and its imaginary part to give $o = q_1 + Iq_2$: q_1 and q_2 are quaternionis and I is octonionic imaginary unit in the complement of the quaternionic sub-space. This decomposition actually appears in the standard construction of octonions. Therefore 4-dimensional surfaces at which the imaginary part of octonion valued function vanishes make sense and defined in well-defined sense quaternionic 4-surfaces.

   This kind of definition would be in nice accord with the vision about physics as algebraic geometry. Now the algebraic geometry would be extended from complex realm to the octonionic realm since quaternionic surfaces/string world sheets could be regarded as associative/commutative sub-algebras of the algebra of the octionic real-analytic functions.

2. Could these surfaces correspond to quaternionic 4-surfaces defined in terms of the modified gamma matrices or induced gamma matrices? Contrary to the original expectations it will be found that only induced gamma matrices is a plausible option. This would be an enormous simplification and would mean that the theory is exactly solvable in the same sense as string models are: complex analyticity would be replaced with octonion analyticity. I have considered this option in several variants using the notion of real octonion analyticity [27] but have not managed to build any satisfactory scenario.

3. Hyper-complex and complex conformal symmetries would result by a restriction to hyper-complex *resp.* complex sub-manifods of the imbedding space defined by string world sheets *resp.* partonic 2-surfaces. The principle forcing this restriction would be commutativity. Yangian of an affine algebra would unify these views to single coherent view [31].

   4-D n-point functions of the theory should result from the restriction on partonic 2-surfaces or string world sheets with arguments of n-point functions identified as the ends of braid strands so that a kind of analytic continuation from 2-D to the 4-D case would be in question. The octonionic conformal invariance would be induced by the ordinary conformal invariance in accordance with strong form of General Coordinate Invariance.

4. This algebraic continuation of the ordinary conformal invariance could help to construct also the representations of Yangians of affine Kac-Moody type algebras. For the Yangian symmetry of 1+1 D integrable QFTs the charges are multilocal involving multiple integrals over ordered multiple points of 1-D space. I

   In the recent case multiple 1-D space is replaced with a space-like 3-surface at the light-like end of CD. The point of the 1-D space appearing in the multiple integral are replaced by a partonic 2-surface represented by a collection of punctures. There is a strong temptation to assume that the intermediate points on the line correspond to genuine physical particles and therefore to partonic 2-surfaces at which the signature of the induced metric changes. If so, the 1-D space would correspond to a closed curve connecting punctures of different partonic 2-surfaces representing physical particles and ordered along a loop. The integral over multiple points would correspond to an integral over WCW rather than over fixed back-ground space-time.

   1-D space would be replaced with a closed curve going through punctures of a subset of partonic 2-surfaces associated with a space-like 3-surface. If a given partonic surface or a given puncture can contribute only once to the multiple integral the multi-locality is bounded from above and only a finite number of Yangian generators are obtained in this manner unless one allows the number of partonic 2-surfaces and of punctures for them to vary. This variation is physically natural and would correspond to generation of particle pairs by vacuum polarization. Although only punctures would contribute, the Yangian charges would be defined in WCW rather than in fixed space-time. Integral over positions of punctures and possible numbers of them would be actually an integral over WCW. 2-D modular invariance of Yangian charges for the partonic 2-surfaces is a natural constraint.

   The question is whether some conformal fields at the punctures of the partonic 2-surfaces appearing in the multiple integral define the basic building bricks of the conserved quantum charges representing the multilocal generators of the Yangian algebra? Note that Wick rotation would be involved.

5.3.2 What the non-triviality of the moduli space of the octonionic structures means?

The moduli space G_2 of the octonionic structures is essentially the Galois group defined as maps of octonions to itself respecting octonionic sum and multiplication. This raises the question whether octonion analyticity should be generalized in such a manner that the global choice of the octonionic imaginary units - in particular that of preferred commuting complex sub-space- would become local. Physically this would correspond to the choice of momentum plane M_x^2 for a position dependent light-iike momentum defining the plane of non-physical polarizations.

This question is inspired by the general solution ansatz based on the slicing of space-time sheets which involves the dependence of the choice of the momentum plane M_x^2 on the point of string world sheet. This dependence is parameterized by a point of $G_2/SU(3)$ and assumed to be constant along partonic 2-surfaces. These slicings would be naturally associated with the two complex parts c_i of the quaternionic coordinate $q_1 = c_1 + Ic_2$ of the space-time sheet.

This dependence is well-defined only for the quaternionic 4-surface defining the space-time surface and can be seen as a local choice of a preferred complex imaginary unit along string world sheets. CP_2 would parametrize the remaining geometric degrees of freedom. Should/could one extend this dependence to entire 8-D imbedding space? This is possible if the 8-D imbedding space allows a slicing by the string world sheets. If the string world sheets correspond to the string world sheets appearing in the slicing of M^4 defined by Hamiton-Jacobi coordinates [3], this slicing indeed exists.

5.3.3 Zero energy ontology and octonion analyticity

How does this picture relate to zero energy ontology and how partonic 2-surfaces and string world sheets could be identified in this framework?

1. The intersection of the quaternionic four-surfaces with the 7-D light-like boundaries of CDs is 3-D space-like surface. String world sheets are obtained as 2-D complex surfaces by putting $c_2 = 0$, where c_2 is the imaginary part of the quaternion coordinate $q = c_1 + Ic_2$. Their intersections with CD boundaries are generally 1-dimensional and represent space-like strings.

2. Partonic 2-surfaces could correspond to the intersections of $Re(c_1) = constant$ 3-surfaces with the boundaries of CD. The variation of $Re(c_1)$ would give a family of (possibly light-like) 3-surfaces whose intersection with the boundaries of CD would be 2-dimensional. The interpretation $Re(c_1) = constant$ surfaces as (possibly light-like) orbits of partonic 2-surfaces would be natural. Wormhole throats at which the signature of the induced metric changes (by definition) would correspond to some special value of $Re(c_1)$, naturally $Re(c_1) = 0$.

   What comes first in mind is that partonic 2-surfaces assignable to wormhole throats correspond to co-complex 2-surfaces obtained by putting $c_1 = 0$ (or $c_1 = constant$) in the decomposition $q = c_1 + ic_2$. This option is consistent with the above assumption if $Im(c_1) = 0$ holds true at the boundaries of CD. Note that also co-quaternionic surfaces make sense and would have Euclidian signature of the induced metric: the interpretation as counterparts of lines of generalized Feynman graphs might make sense.

3. One can of course wonder whether also the poles of c_1 might be relevant. The most natural idea is that the value of $Re(c_1)$ varies between 0 and ∞ between the ends of the orbit of partonic 2-surface. This would mean that c_1 has a pole at the other end of CD (or light-like orbit of partonic 2-surface). In light of this the earlier proposal [25] that zero energy states might correspond to rational functions assignable to infinite primes and that the zeros/poles of these functions correspond to the positive/negative energy part of the state is interesting.

   The intersections of string world sheets and partonic 2-surfaces identifiable as the common ends of space-like and time like brand strands would correspond to the points $q = c_1 + Ic_2 = 0$ and $q = \infty + Ic_2$, where ∞ means real infinity. In other words, to the zeros and real poles of quaternion analytic function with real coefficients. In the number theoretic vision especially interesting situations correspond to polynomials with rational number valued coefficients and rational functions formed from these. In this kind of situations the number of zeros and therefore of braid strands is always finite.

5.3.4 Do induced or modified gamma matrices define quaternionicity?

The are two options to be considered: either induced or modified gamma matrices define quaternionicity.

1. There are several arguments supporting this view that induced gamma matrices define quaternionicity and that quaternionic planes are therefore tangent planes for space-time sheet.

   (a) $H - M^8$ correspondence is based on the observation that quaternionic sub-spaces of octonions containing preferred complex sub-space are labelled by points of CP_2. The integrability of the distribution of quaternionic spaces could follow from the parametrization by points of CP_2 ($CP_2 = CP_{mod}$ condition). Quaternionic planes would be necessarily tangent planes of space-time surface. Induced gamma matrices correspond naturally to the tangent space vectors of the space-time surface.

   Here one should however understand the role of the M^4 coordinates. What is the functional form of M^4 coordinates as functions of space-time coordinates or does this matter at all (general coordinate invariance): could one choose the space-time coordinates as M^4 coordinates for surfaces representable as graphs for maps $M^4 \to CP_2$? What about other cases such as cosmic strings [8]?

   (b) Could one do entirely without gamma matrices and speak only about induced octonion structure in 8-D tangent space (raising also dimension $D = 8$ to preferred role) with reduces to quaternionic structure for quaternionic 4-surfaces. The interpretation of quaternionic plane as tangent space would be unavoidable also now. In this approach there would be no question about whether one should identify octonionic gamma matrices as induced gamma matrices or as modified octonionic gamma matrices.

   (c) If quaternion analyticity is defined in terms of modified gamma matrices defined by the volume action why it would solve the field equations for Kähler action rather than for minimal surfaces? Is the reason that quaternionic and octonionic analyticities defined as generalized differentiability are not possible. The real and imaginary parts of quaternionic real-analytic function with quaternion interpreted as bi-complex number are not analytic functions of two complex variables of either complex variable. In 4-D situation minimal surface property would be too strong a condition whereas Kähler action poses much weaker conditions. Octonionic real-analyticity however poses strong symmetries and suggests effective 2-dimensionality.

2. The following argument suggest that modified gamma matrices cannot define the notion of quaternionic plane.

   (a) Modified gamma matrices can define sub-spaces of lower dimensionality so that they do not defined a 4-plane. In this case they cannot define CP_2 point so that $CP_2 = CP_2^{mod}$ identity fails. Massless extremals represents the basic example about this. Hydrodynamic solutions defined in terms of Beltrami flows could represent a more general phase of this kind.

   (b) Modified gamma matrices are not in general parallel to the space-time surface. The CP_2 part of field equations coming from the variation of Kähler form gives the non-tangential contribution. If the distribution of the quaternionic planes is integrable it defines another space-time surface and this looks rather strange.

   (c) Integrable quaternionicity can mean only tangent space quaternionicity. For modified gamma matrices this cannot be the case. One cannot assign to the octonion analytic map modified gamma matrices in any natural manner.

The conclusion seems to be that induced gamma matrices or induced octonion structure must define quaternionicity and quaternionic planes are tangent planes of space-time surface and therefore define an integrable distribution. An open question is whether $CP_2 = CP_2^{mod}$ condition implies the integrability automatically.

5.3.5 Volume action or Kähler action?

What seems clear is that quaternionicity must be defined by the induced gamma matrices obtained as contractions of canonical momentum densities associated with volume action with imbedding space gamma matrices. Probably equivalent definition is in terms of induced octonion structure. For the believer in strings this would suggest that the volume action is the correct choice. There are however strong objections against this choice.

1. In 2-dimensional case the minimal surfaces allow conformal invariance and one can speak of complex structure in their tangent space. In particular, string world sheets can be regarded as complex 2-surfaces of quaternionic space-time surfaces. In 4-dimensional case the situation is different since quaternionic differentiability fails by non-commutativity. It is quite possible that only very few minimal surfaces (volume action) are quaternionic.

2. The possibility of Beltrami flows is a rather plausible property of quite many preferred extremals of Kähler action. Beltrami flows are also possible for a 4-D minimal surface action. In particular, M^4 translations would define Beltrami flows for which the 1-forms would be gradients of linear M^4 coordinates. If M^4 coordinate can be used on obtains flows in directions of all coordinate axes. Hydrodynamical picture in the strong form therefore fails whereas for Kähler action various isometry currents could be parallel (as they are for massless extremals).

3. For volume action topological QFT property fails as also fails the decomposition of solutions to massless quanta in Minkowskian regions. The same applies to criticality. The crucial vacuum degeneracy responsible for most nice features of Kähler action is absent and also the effective 2-dimensionality and almost topological QFT property are lost since the action does not reduce to 3-D term.

One can however keep Kähler action and define quaternionicity in terms of induced gamma matrices or induced octonion structure. Preferred extremals could be identified as extremals of Kähler action which are also quaternionic 4-surfaces.

1. Preferred extremal property for Kähler action could be much weaker condition than minimal surface property so that much larger set of quaternionic space-time surfaces would be extremals of the Kähler action than of volume action. The reason would be that the rank of energy momentum tensor for Maxwell action tends to be smaller than maximal. This expectation is supported by the vacuum degeneracy, the properties of massless extremals and of CP_2 type vacuum extremals, and by the general hydrodynamical picture.

2. There is also a long list of beautiful properties supporting Kähler action which should be also familiar: effective 2-dimensionality and slicing of space-time surface by string world sheets and partonic 2-surfaces, reduction to almost topological QFT and to abelian Chern-Simons term, weak form of electric-magnetic duality, quantum criticality, spin glass degeneracy, etc...

5.3.6 Are quaternionicities defined in terms of induced gamma matrices *resp.* octonion real-analytic maps equivalent?

Quaternionicity could be defined by induced gamma matrices or in terms of octonion real-analytic maps. Are these two definitions equivalent and how could one test the equivalence?

1. The calculation technical problem is that space-time surfaces are not defined in terms of imbedding map involving some coordinate choice but in terms of four vanishing conditions for the imaginary part of the octonion real-analytic function expressible as biquaternion valued functions.

2. Integrability to 4-D surface is achieved if there exists a 4-D closed Lie algebra defined by vector fields identifiable as tangent vector fields. This Lie algebra can be generalized to a local 4-D Lie algebra. One cannot however represent octonionic units in terms of 8-D vector fields since the commutators of the latter do not form an associative algebra. Also the representation of 7 octonionic imaginary units as 8-D vector fields is impossible since the algebra in question is non-assciative Malcev algebra [3] which can be seen as a Lie algebra over non-associative number

field (one speaks of 7-dimensional cross product [7]). One must use instead of vector fields either octonionic units as such or octonionic gamma "matrices" to represent tangent vectors. The use of octonionic units as such would mean the introduction of the notion of octonionic tangent space structure. That the subalgebra generated by any two octonionic units is associative brings strongly in mind effective 2-dimensionality.

3. The tangent vector fields of space-time surface in the representation using octonionic units can be identified in the following manner. Map can be defined using 8-D octonionic coordinates defined by standard M^4 coordinates or possibly Hamilton-Jacobi coordinates and CP_2 complex coordinates for which U(2) is represented linearly. Gamma "matrices" for H using octonionic representation are known in these coordinates. One can introduce the 8 components of the image of a given point under the octonion real-analytic map as new imbedding space coordinates. One can calculate the covariant gamma matrices of H in these coordinates.

   What should check whether the octonionic gamma matrices associated with the four non-vanishing coordinates define quaternionic (and thus associative) algebra in the octonionic basis for the gamma matrices. Also the interpretation as a associative subspace of local Malcev algebra elements is possible and one should check whether if the algebra reduces to a quaternionic Lie-algebra. Local $SO(2) \times U(1)$ algebra should emerge in this manner.

4. Can one identify quaternionic imaginary units with vector fields generating SO(3) Lie algebra or its local variant? The Lie algebra of rotation generators defines algebra equivalent with that based on commutars of quaternionic units. Could the slicing of space-time sheet by time axis define local $SO(3)$ algebra? Light-like momentum direction and momentum direction and its dual define as their sum space-like vector field and together with vector fields defining transversal momentum directions they might generate a local $SO(3)$ algebra.

5.3.7 Questions related to quaternion real-analyticity

There are many poorly understood issues and and the following questions represent only some of very many such questions picked up rather randomly.

1. The above considerations are restricted to Minkowskian regions of space-time sheets. What happens in the Euclidian regions? Does the existence of light-like Beltrami field and its dual generalize to the existence of complex vector field and its dual?

2. It would be nice to find a justification for the notion of CD from basic principles. The condition $q\overline{q} = 0$ implies $q = 0$ for quaternions. For hyper-quaternionic subspace of complexified quaternions obtained by Wick rotation it implies $q\overline{q} = 0$ corresponds the entire light-cone boundary. If n-point functions can be identified identified as products of quaternion valued n-point functions and their quaternionic conjugates, the outcome could be proportional to $1/q\overline{q}$ having poles at light-cone boundaries or CD boundaries rather than at single point as in Euclidian realm.

3. This correspondence of points and light-cone boundaries would effectively identify the points at future and past light-like boundaries of CD along light rays. Could one think that only the 2-sphere at which the upper and lower light-like boundaries of CD meet remains after this identification. The structure would be homologically very much like CP_2 which is obtained by compactifying E^4 by adding a 2-sphere at infinity. Could this $CD - CP_2$ correspondence have some deep physical meaning? Do the boundaries of CD somehow correspond to zeros and/or poles of quaternionic analytic functions in the Minkowskian realm? Could the light-like orbits of partonic 2-surfaces at which the signature of the induced metric changes correspond to similar counterparts of zeros or poles when the quaternion analytic variables is obtained as quaternion real analytic function of H coordinates regarded as bi-quaternions?

4. Could braids correspond to zeros and poles of an octonion real-analytic function? Consider the partonic 2-surfaces at which the signature of the induced metric changes. The intersections of these surfaces with string world sheets at the ends of CDs. contain only complex and thus commutative points meaning that the imaginary part of bi-complex number representing quaternionic value of octonion real-analytic function vanishes. Braid ends would thus correspond to the origins of local complex coordinate patches. Finite measurement resolution would be forced

by commutativity condition and correlate directly with the complexity of the partonic 2-surface measured by the minimal number of coordinate patches. Its realization would be as an upper bound on the number of braid strands. A natural expectation would be that only the values of n-point functions at these points contribute to scattering amplitudes. Number theoretic braids would be realized but in a manner different from the original guess.

5.3.8 How complex analysis could generalize?

One can make several questions related to the possible generalization of complex analysis to the quaternionic and octonionic situation.

1. Does the notion of analyticity in the sense that derivatives df/dq and df/do make sense hold true? The answer is "No": non-commutativity destroys all hopes about this kind of generalization. Octonion and quaternion real-analyticity has however a well-defined meaning.

2. Could the generalization of residue calculus by keeping interaction contours as 1-D curves make sense? Since residue formulas is the outcome of the fact that any analytic function g can be written as $g = df/dz$ locally, the answer is "No".

3. Could one generalize of the residue calculus by replacing 1-dimensional curves with 4-D surfaces -possibly quaternionic 4-surfaces? Could one reduce the 4-D integral of quaternion analytic function to a double residue integral? This would be the case if the quaternion real-analytic function of $q = c_1 + Ic_2$ could be regarded as an analytic function of complex arguments c_1 and c_2. This is not the case. The product of two octonions decomposed to two quaternions as $o_i = q_{i1} + Iq_{i2}$, $i = a, b$ reads as

$$o_a o_b = q_{a1}q_{b1} - \overline{q}_{a2}q_{b2} + I(\overline{q}_{a1}q_{b2} - q_{a2}q_{b1}) \ . \tag{5.6}$$

   The conjugations result from the anticommutativity of imaginary parts and I. This formula gives similar formula for quaternions by restriction. As a special cas $o_a = o_b = q_1 + Iq_2$ one has

$$o^2 = q_1^2 - \overline{q}_2 q_2 + I(\overline{q}_1 q_2 - q_2 q_1)$$

   From this it is clear that the real part of an octonion real-analytic function cannot be regarded as quaternion-analytic function unless one assumes that the imaginary part q_2 vanishes. By similar argument real part of quaternion real-analytic function $q = c_1 + Ic_2$ fails to be analytic unless one restricts the consideration to a surface at which one has $c_2 = 0$. These negative results are obviously consistent with the effective 2-dimensionality.

4. One must however notice that physicists use often what might be called analytization trick [1] working if the non-analytic function $f(x, y) = f(z, \overline{z})$ is differentiable. The trick is to interpret z and $\overline{z}$ as independent variables. In the recent case this is rather natural. Wick rotation could be used to transform the integral over the space-time sheet to integral in quaternionic domain. For 4-dimensional integrals of quaternion real-analytic function with integration measure proportional to $dc_1 d\overline{c}_1 dc_2 d\overline{c}_2$ one could formally define the integral using multiple residue integration with four complex variables. The constraint is that the poles associated with c_i and $\overline{c}_i$ are conjugates of each other. Quaternion real-analyticity should guarantee this. This would of course be a *definition* of four-dimensional integral and might work for the 4-D generalization of conformal field theory.

Mandelbrot and Julia sets are fascinating fractals and already now more or less a standard piece of complex analysis. The fact that the iteration of octonion real-analytic map produces a sequence of space-time surfaces and partonic 2-surfaces encourages to ask whether these notions -and more generally, the dynamics based on iteration of analytic functions - might have a higher-dimensional generalization in the proposed framework.

1. The canonical Mandelbrot set corresponds to the set of the complex parameters c in $f(z) = z^2+c$ for which iterates of $z = 0$ remain finite. In octonionic and quaternionic real-analytic case c would be real so that one would obtain only the intersection of the Mandelbrot set with real axes and the outcome would be rather uninteresting. This is true quite generally.

2. Julia set corresponds to the boundary of the Fatou set in which the dynamics defined by the iteration of $f(z)$ by definition behaves in a regular manner. In Julia set the behavior is chaotic. Julia set can be defined as a set of complex plane resulting by taking inverse images of a generic point belonging to the Julia set. For polynomials Julia set is the boundary of the region in which iterates remain finite. In Julia set the dynamics defined by the iteration is chaotic.

   Julia set could be interesting also in the recent case since it could make sense for real analytic functions of both quaternions and octonions, and one might hope that the dynamics determined by the iterations of octonion real-analytic function could have a physical meaning as a space-time correlate for quantal self-organization by quantum jump in TGD framework. Single step in iteration would be indeed a very natural space-time correlate for quantum jump. The restriction of octonion analytic functions to string world sheets should produce the counterparts of the ordinary Julia sets since these surfaces are mapped to themselves under iteration and octonion real-analytic functions reduces to ordinary complex real-analytic functions at them. Therefore one might obtain the counterparts of Julia sets in 4-D sense as extensions of ordinary Julia sets. These extensions would be 3-D sets obtained as piles of ordinary Julia sets labelled by partonic 2-surfaces.

6 Does modified Dirac action define the fundamental action principle?

Although quantum criticality in principle predicts the possible values of Kähler coupling strength, one might hope that there exists even more fundamental approach involving no coupling constants and predicting even quantum criticality and realizing quantum gravitational holography. The Dirac determinant associated with the modified Dirac action is an excellent candidate in this respect.

The original working hypothesis was that Dirac determinant defines the vacuum functional of the theory having interpretation as the exponent of Kähler function of world of classical worlds (WCW) expressible and that Kähler function reduces to Kähler action for a preferred extremal of Kähler action.

6.1 What are the basic equations of quantum TGD?

A good place to start is to as what might the basic equations of quantum TGD. There are two kinds of equations at the level of space-time surfaces.

1. Purely classical equations define the dynamics of the space-time sheets as preferred extremals of Kähler action. Preferred extremals are quantum critical in the sense that second variation vanishes for critical deformations representing zero modes. This condition guarantees that corresponding fermionic currents are conserved. There is infinite hierarchy of these currents and they define fermionic counterparts for zero modes. Space-time sheets can be also regarded as hyper-quaternionic surfaces. What these statements precisely mean has become clear only during this year. A rigorous proof for the equivalence of these two identifications is still lacking.

2. The purely quantal equations are associated with the representations of various super-conformal algebras and with the modified Dirac equation. The requirement that there are deformations of the space-time surface -actually infinite number of them- giving rise to conserved fermionic charges implies quantum criticality at the level of Kähler action in the sense of critical deformations. The precise form of the modified Dirac equation is not however completely fixed without further input. Quantal equations involve also generalized Feynman rules for M-matrix generalizing S-matrix to a "complex square root" of density matrix and defined by time-like entanglement coefficients between positive and negative energy parts of zero energy states is certainly the basic goal of quantum TGD.

3. The notion of weak electric-magnetic duality generalizing the notion of electric-magnetic duality [11] , [5] leads to a detailed understanding of how TGD reduces to almost topological quantum field theory [11] , [5] . If Kähler current defines Beltrami flow [3] it is possible to find a gauge in which Coulomb contribution to Kähler action vanishes so that it reduces to Chern-Simons term. If light-like 3-surfaces and ends of space-time surface are extremals of Chern-Simons action also effective 2-dimensionality is realized. The condition that the theory reduces to almost topological QFT and the hydrodynamical character of field equations leads to a detailed ansatz for the general solution of field equations and also for the solutions of the modified Dirac equation relying on the notion of Beltrami flow for which the flow parameter associated with the flow lines defined by a conserved current extends to a global coordinate. This makes the theory is in well-defined sense completely integrable. Direct connection with massless theories emerges: every conserved Beltrami currents corresponds to a pair of scalar functions with the first one satisfying massless d'Alembert equation in the induced metric. The orthogonality of the gradients of these functions allows interpretation in terms of polarization and momentum directions. The Beltrami flow property can be also seen as one aspect of quantum criticality since the conserved currents associated with critical deformations define this kind of pairs.

4. The hierarchy of Planck constants provides also a fresh view to the quantum criticality. The original justification for the hierarchy of Planck constants came from the indications that Planck constant could have large values in both astrophysical systems involving dark matter and also in biology. The realization of the hierarchy in terms of the singular coverings and possibly also factor spaces of CD and CP_2 emerged from consistency conditions. It however seems that TGD actually predicts this hierarchy of covering spaces. The extreme non-linearity of the field equations defined by Kähler action means that the correspondence between canonical momentum densities and time derivatives of the imbedding space coordinates is 1-to-many. This leads naturally to the introduction of the covering space of $CD \times CP_2$, where CD denotes causal diamond defined as intersection of future and past directed light-cones.

At the level of WCW there is the generalization of the Dirac equation which can be regarded as a purely classical Dirac equation. The modified Dirac operators associated with quarks and leptons carry fermion number but the Dirac equations are well-defined. An orthogonal basis of solutions of these Dirac operators define in zero energy ontology a basis of zero energy states. The M-matrices defining entanglement between positive and negative energy parts of the zero energy state define what can be regarded as analogs of thermal S-matrices. The M-matrices associated with the solution basis of the WCW Dirac equation define by their orthogonality unitary U-matrix between zero energy states. This matrix finds the proper interpretation in TGD inspired theory of consciousness. WCW Dirac equation as the analog of super-Virasoro conditions for the "gamma fields" of superstring models defining super counterparts of Virasoro generators was the main focus during earlier period of quantum TGD but has not received so much attention lately and will not be discussed in this chapter.

6.2 Quantum criticality and modified Dirac action

The precise mathematical formulation of quantum criticality has remained one of the basic challenges of quantum TGD. The question leading to a considerable progress in the problem was simple: Under what conditions the modified Dirac action allows to assign conserved fermionic currents with the deformations of the space-time surface? The answer was equally simple: These currents exists only if these deformations correspond to vanishing second variations of Kähler action - which is what criticality is. The vacuum degeneracy of Kähler action strongly suggests that the number of critical deformations is always infinite and that these deformations define an infinite inclusion hierarchy of super-conformal algebras. This inclusion hierarchy would correspond to a fractal hierarchy of breakings of super-conformal symmetry generalizing the symmetry breaking hierarchies of gauge theories. These super-conformal inclusion hierarchies would realize the inclusion hierarchies for hyper-finite factors of type II_1.

6.2.1 Quantum criticality and fermionic representation of conserved charges associated with second variations of Kähler action

It is rather obvious that TGD allows a huge generalizations of conformal symmetries. The development of the understanding of conservation laws has been slow. Modified Dirac action provides excellent candidates for quantum counterparts of Noether charges. Unfortunately, the isometry charges vanish for Cartan algebras. The only manner to obtain non-trivial isometry charges is to add a direct coupling to the charges in Cartan algebra as will be found later. This addition involves Chern-Simons Dirac action so that the original intuition guided by almost TQFT idea was not wrong after all.

1. Conservation of the fermionic current requires the vanishing of the second variation of Kähler action

1. The modified Dirac action assigns to a deformation of the space-time surface a conserved charge expressible as bilinears of fermionic oscillator operators only if the first variation of the modified Dirac action under this deformation vanishes. The vanishing of the first variation for the modified Dirac action is equivalent with the vanishing of the second variation for the Kähler action. This can be seen by the explicit calculation of the second variation of the modified Dirac action and by performing partial integration for the terms containing derivatives of Ψ and $\overline{\Psi}$ to give a total divergence representing the difference of the charge at upper and lower boundaries of the causal diamond plus a four-dimensional integral of the divergence term defined as the integral of the quantity

$$\begin{aligned} \Delta S_D &= \overline{\Psi}\Gamma^k D_\alpha J^\alpha_k \Psi \ , \\ J^\alpha_k &= \frac{\partial^2 L_K}{\partial h^k_\alpha \partial h^l_\beta}\delta h^k_\beta + \frac{\partial^2 L_K}{\partial h^k_\alpha \partial h^l}\delta h^l \ . \end{aligned} \tag{6.1}$$

Here h^k_β denote partial derivative of the imbedding space coordinate with respect to space-time coordinates. This term must vanish:

$$D_\alpha J^\alpha_k = 0 \ .$$

The condition states the vanishing of the second variation of Kähler action. This can of course occur only for preferred deformations of X^4. One could consider the possibility that these deformations vanish at light-like 3-surfaces or at the boundaries of CD. Note that covariant divergence is in question so that J^α_k does not define conserved classical charge in the general case.

2. It is essential that the modified Dirac equation holds true so that the modified Dirac action vanishes: this is needed to cancel the contribution to the second variation coming from the determinant of the induced metric. The condition that the modified Dirac equation is satisfied for the deformed space-time surface requires that also Ψ suffers a transformation determined by the deformation. This gives

$$\delta\Psi = -\frac{1}{D} \times \Gamma^k J^\alpha_k \Psi \ . \tag{6.2}$$

Here $1/D$ is the inverse of the modified Dirac operator defining the counterpart of the fermionic propagator.

3. The fermionic conserved currents associated with the deformations are obtained from the standard conserved fermion current

$$J^\alpha = \overline{\Psi}\Gamma^\alpha \Psi \ . \tag{6.3}$$

Note that this current is conserved only if the space-time surface is extremal of Kähler action: this is also needed to guarantee Hermiticity and same form for the modified Dirac equation for Ψ and its conjugate as well as absence of mass term essential for super-conformal invariance [6, 8] . Note also that ordinary divergence rather only covariant divergence of the current vanishes.

The conserved currents are expressible as sums of three terms. The first term is obtained by replacing modified gamma matrices with their increments in the deformation keeping Ψ and its conjugate constant. Second term is obtained by replacing Ψ with its increment $\delta\Psi$. The third term is obtained by performing same operation for $\delta\overline{\Psi}$.

$$J^{\alpha} = \overline{\Psi}\Gamma^k J_k^{\alpha}\Psi + \overline{\Psi}\hat{\Gamma}^{\alpha}\delta\Psi + \delta\overline{\Psi}\hat{\Gamma}^{\alpha}\Psi \ . \tag{6.4}$$

These currents provide a representation for the algebra defined by the conserved charges analogous to a fermionic representation of Kac-Moody algebra [2] .

4. Also conserved super charges corresponding to super-conformal invariance are obtained. The first class of super currents are obtained by replacing Ψ or $\overline{\Psi}$ right-handed neutrino spinor or its conjugate in the expression for the conserved fermion current and performing the above procedure giving two terms since nothing happens to the covariantly constant right handed-neutrino spinor. Second class of conserved currents is defined by the solutions of the modified Dirac equation interpreted as c-number fields replacing Ψ or $\overline{\Psi}$ and the same procedure gives three terms appearing in the super current.

5. The existence of vanishing of second variations is analogous to criticality in systems defined by a potential function for which the rank of the matrix defined by second derivatives of the potential function vanishes at criticality. Quantum criticality becomes the prerequisite for the existence of quantum theory since fermionic anti-commutation relations in principle can be fixed from the condition that the algebra in question is equivalent with the algebra formed by the vector fields defining the deformations of the space-time surface defining second variations. Quantum criticality in this sense would also select preferred extremals of Kähler action as analogs of Bohr orbits and the the spectrum of preferred extremals would be more or less equivalent with the expected existence of infinite-dimensional symmetry algebras.

2. About the general structure of the algebra of conserved charges

Some general comments about the structure of the algebra of conserved charges are in order.

1. Any Cartan algebra of the isometry group $P \times SU(3)$ (there are two types of them for P corresponding to linear and cylindrical Minkowski coordinates) defines critical deformations (one could require that the isometries respect the geometry of CD). The corresponding charges are conserved but vanish since the corresponding conjugate coordinates are cyclic for the Kähler metric and Kähler form so that the conserved current is proportional to the gradient of a Killing vector field which is constant in these coordinates. Therefore one cannot represent isometry charges as fermionic bilinears. Four-momentum and color quantum numbers are defined for Kähler action as classical conserved quantities but this is probably not enough. This can be seen as a problem.

   (a) Four-momentum and color Cartan algebra emerge naturally in the representations of super-conformal algebras. In the case of color algebra the charges in the complement of the Cartan algebra can be constructed in standard manner as extension of those for the Cartan algebra using free field representation of Kac-Moody algebras. In string theories four-momentum appears linearly in bosonic Kac-Moody generators and in Sugawara construction [16] of super Virasoro generators as bilinears of bosonic Kac-Moody generators and fermionic super Kac-Moody generators [2] . Also now quantized transversal parts for M^4 coordinates could define a second quantized field having interpretation as an operator acting on spinor fields of WCW. The angle coordinates conjugate to color isospin and hyper charge take the role of M^4 coordinates in case of CP_2.

(b) Somehow one should be able to feed the information about the super-conformal representation of the isometry charges to the modified Dirac action by adding to it a term coupling fermionic current to the Cartan charges in general coordinate invariant and isometry invariant manner. As will be shown later, this is possible. The interpretation is as measurement interaction guaranteeing also the stringy character of the fermionic propagators. The values of the couplings involved are fixed by the condition of quantum criticality assumed in the sense that Kähler function of WCW suffers only a $U(1)$ gauge transformation $K \rightarrow K + f + \overline{f}$, where f is a holomorphic function of WCW coordinates depending also on zero modes.

(c) The simplest addition involves the modified gamma matrices defined by a Chern-Simon term at the light-like wormhole throats and is sum of Chern-Simons Dirac action and corresponding coupling term linear in Cartan charges assignable to the partonic 2-surfaces at the ends of the throats. Hence the modified Dirac equation in the interior of the space-time sheet is not affected and nothing changes as far as quantum criticality in interior is considered.

2. The action defined by four-volume gives a first glimpse about what one can expect. In this case modified gamma matrices reduce to the induced gamma matrices. Second variations satisfy d'Alembert type equation in the induced metric so that the analogs of massless fields are in question. Mass term is present only if some dimensions are compact. The vanishing of excitations at light-like boundaries is a natural boundary condition and might well imply that the solution spectrum could be empty. Hence it is quite possible that four-volume action leads to a trivial theory.

3. For the vacuum extremals of Kähler action the situation is different. There exists an infinite number of second variations and the classical non-determinism suggests that deformations vanishing at the light-like boundaries exist. For the canonical imbedding of M^4 the equation for second variations is trivially satisfied. If the CP_2 projection of the vacuum extremal is one-dimensional, the second variation contains a on-vanishing term and an equation analogous to massless d'Alembert equation for the increments of CP_2 coordinates is obtained. Also for the vacuum extremals of Kähler action with 2-D CP_2 projection all terms involving induced Kähler form vanish and the field equations reduce to d'Alembert type equations for CP_2 coordinates. A possible interpretation is as the classical analog of Higgs field. For the deformations of non-vacuum extremals this would suggest the presence of terms analogous to mass terms: these kind of terms indeed appear and are proportional to δs^k. M^4 degrees of freedom decouple completely and one obtains QFT type situation.

4. The physical expectation is that at least for the vacuum extremals the critical manifold is infinite-dimensional. The notion of finite measurement resolution suggests infinite hierarchies of inclusions of hyper-finite factors of type II_1 possibly having interpretation in terms of inclusions of the super conformal algebras defined by the critical deformations.

5. The properties of Kähler action give support for this expectation. The critical manifold is infinite-dimensional in the case of vacuum extremals. Canonical imbedding of M^4 would correspond to maximal criticality analogous to that encountered at the tip of the cusp catastrophe. The natural guess would be that as one deforms the vacuum extremal the previously critical degrees of freedom are transformed to non-critical ones. The dimension of the critical manifold could remain infinite for all preferred extremals of the Kähler action. For instance, for cosmic string like objects any complex manifold of CP_2 defines cosmic string like objects so that there is a huge degeneracy is expected also now. For CP_2 type vacuum extremals M^4 projection is arbitrary light-like curve so that also now infinite degeneracy is expected for the deformations.

3. Critical super algebra and zero modes

The relationship of the critical super-algebra to configuration space geometry is interesting.

1. The vanishing of the second variation plus the identification of Kähler function as a Kähler action for preferred extremals means that the critical variations are orthogonal to all deformations of

the space-time surface with respect to the configuration space metric and thus correspond to zero modes. This conforms with the fact that configuration space metric vanishes identically for canonically imbedded M^4. Zero modes do not seem to correspond to gauge degrees of freedom so that the super-conformal algebra associated with the zero modes has genuine physical content.

2. Since the action of X^4 local Hamiltonians of $\delta M^4_\times CP_2$ corresponds to the action in quantum fluctuating degrees of freedom, critical deformations cannot correspond to this kind of Hamiltonians.

3. The notion of finite measurement resolution suggests that the degrees of freedom which are below measurement resolution correspond to vanishing gauge charges. The sub-algebras of critical super-conformal algebra for which charges annihilate physical states could correspond to this kind of gauge algebras.

4. The conserved super charges associated with the vanishing second variations cannot give configuration space metric as their anti-commutator. This would also lead to a conflict with the effective 2-dimensionality stating that the configuration space line-element is expressible as sum of contribution coming from partonic 2-surfaces as also with fermionic anti-commutation relations.

4. Connection with quantum criticality

The vanishing of the second variation for some deformations means that the system is critical, in the recent case quantum critical. Basic example of criticality is bifurcation diagram for cusp catastrophe. For some mysterious reason I failed to realize that quantum criticality realized as the vanishing of the second variation makes possible a more or less unique identification of preferred extremals and considered alternative identifications such as absolute minimization of Kähler action which is just the opposite of criticality. Both the super-symmetry of D_K and conservation Dirac Noether currents for modified Dirac action have thus a connection with quantum criticality.

1. Finite-dimensional critical systems defined by a potential function $V(x^1, x^2, ..)$ are characterized by the matrix defined by the second derivatives of the potential function and the rank of system classifies the levels in the hierarchy of criticalities. Maximal criticality corresponds to the complete vanishing of this matrix. Thom's catastrophe theory classifies these hierarchies, when the numbers of behavior and control variables are small (smaller than 5). In the recent case the situation is infinite-dimensional and the criticality conditions give additional field equations as existence of vanishing second variations of Kähler action.

2. The vacuum degeneracy of Kähler action allows to expect that this kind infinite hierarchy of criticalities is realized. For a general vacuum extremal with at most 2-D CP_2 projection the matrix defined by the second variation vanishes because $J_{\alpha\beta} = 0$ vanishes and also the matrix $(J^{\alpha}_{\ k} + J_k^{\ \alpha})(J^{\beta}_{\ l} + J_l^{\ \beta})$ vanishes by the antisymmetry $J^{\alpha}_{\ k} = -J_k^{\ \alpha}$. Recall that the formulation of Equivalence Principle in string picture demonstrated that the reduction of stringy dynamics to that for free strings requires that second variation with respect to M^4 coordinates vanish. This condition would guarantee the conservation of fermionic Noether currents defining gravitational four-momentum and other Poincare quantum numbers but not those for gravitational color quantum numbers. Encouragingly, the action of CP_2 type vacuum extremals having random light-like curve as M^4 projection have vanishing second variation with respect to M^4 coordinates (this follows from the vanishing of Kähler energy momentum tensor, second fundamental form, and Kähler gauge current). In this case however the momentum is vanishing.

3. Conserved bosonic and fermionic Noether charges would characterize quantum criticality. In particular, the isometries of the imbedding space define conserved currents represented in terms of the fermionic oscillator operators if the second variations defined by the infinitesimal isometries vanish for the modified Dirac action. For vacuum extremals the dimension of the critical manifold is infinite: maybe there is hierarchy of quantum criticalities for which this dimension decreases step by step but remains always infinite. This hierarchy could closely relate to the hierarchy of inclusions of hyper-finite factors of type II_1. Also the conserved charges associated with Super-symplectic and Super Kac-Moody algebras would require infinite-dimensional critical manifold defined by the spectrum of second variations.

4. Phase transitions are characterized by the symmetries of the phases involved with the transitions, and it is natural to expect that dynamical symmetries characterize the hierarchy of quantum criticalities. The notion of finite quantum measurement resolution based on the hierarchy of Jones inclusions indeed suggests the existence of a hierarchy of dynamical gauge symmetries characterized by gauge groups in ADE hierarchy [10] with degrees of freedom below the measurement resolution identified as gauge degrees of freedom.

5. A breakthrough in understanding of the criticality was the discovery that the realization that the hierarchy of singular coverings of $CD \times CP_2$ needed to realize the hierarchy of Planck constants could correspond directly to a similar hierarchy of coverings forced by the factor that classical canonical momentum densities correspond to several values of the time derivatives of the imbedding space coordinates led to a considerable progress if the understanding of the relationship between criticality and hierarchy of Planck constants [12] , [2] . Therefore the problem which led to the geometrization program of quantum TGD, also allowed to reduce the hierarchy of Planck constants introduced on basis of experimental evidence to the basic quantum TGD. One can say that the 3-surfaces at the ends of CD *resp.* wormhole throats are critical in the sense that they are unstable against splitting to n_b *resp.* n_a surfaces so that one obtains space-time surfaces which can be regarded as surfaces in $n_a \times n_b$ fold covering of $CD \times CP_2$. This allows to understand why Planck constant is effectively replaced with $n_a n_b \hbar_0$ and explains charge fractionization.

6.2.2 Preferred extremal property as classical correlate for quantum criticality, holography, and quantum classical correspondence

The Noether currents assignable to the modified Dirac equation are conserved only if the first variation of the modified Dirac operator D_K defined by Kähler action vanishes. This is equivalent with the vanishing of the second variation of Kähler action -at least for the variations corresponding to dynamical symmetries having interpretation as dynamical degrees of freedom which are below measurement resolution and therefore effectively gauge symmetries.

The vanishing of the second variation in interior of $X^4(X^3_l)$ is what corresponds exactly to quantum criticality so that the basic vision about quantum dynamics of quantum TGD would lead directly to a precise identification of the preferred extremals. Something which I should have noticed for more than decade ago! The question whether these extremals correspond to absolute minima remains however open.

The vanishing of second variations of preferred extremals -at least for deformations representing dynamical symmetries, suggests a generalization of catastrophe theory of Thom, where the rank of the matrix defined by the second derivatives of potential function defines a hierarchy of criticalities with the tip of bifurcation set of the catastrophe representing the complete vanishing of this matrix. In the recent case this theory would be generalized to infinite-dimensional context. There are three kind of variables now but quantum classical correspondence (holography) allows to reduce the types of variables to two.

1. The variations of $X^4(X^3_l)$ vanishing at the intersections of $X^4(X^3_l)$ wth the light-like boundaries of causal diamonds CD would represent behavior variables. At least the vacuum extremals of Kähler action would represent extremals for which the second variation vanishes identically (the "tip" of the multi-furcation set).

2. The zero modes of Kähler function would define the control variables interpreted as classical degrees of freedom necessary in quantum measurement theory. By effective 2-dimensionality (or holography or quantum classical correspondence) meaning that the configuration space metric is determined by the data coming from partonic 2-surfaces X^2 at intersections of X^3_l with boundaries of CD, the interiors of 3-surfaces X^3 at the boundaries of CDs in rough sense correspond to zero modes so that there is indeed huge number of them. Also the variables characterizing 2-surface, which cannot be complexified and thus cannot contribute to the Kähler metric of configuration space represent zero modes. Fixing the interior of the 3-surface would mean fixing of control variables. Extremum property would fix the 4-surface and behavior variables if boundary conditions are fixed to sufficient degree.

3. The complex variables characterizing X^2 would represent third kind of variables identified as quantum fluctuating degrees of freedom contributing to the configuration space metric. Quantum classical correspondence requires 1-1 correspondence between zero modes and these variables. This would be essentially holography stating that the 2-D "causal boundary" X^2 of $X^3(X^2)$ codes for the interior. Preferred extremal property identified as criticality condition would realize the holography by fixing the values of zero modes once X^2 is known and give rise to the holographic correspondence $X^2 \rightarrow X^3(X^2)$. The values of behavior variables determined by extremization would fix then the space-time surface $X^4(X^3_l)$ as a preferred extremal.

4. Clearly, the presence of zero modes would be absolutely essential element of the picture. Quantum criticality, quantum classical correspondence, holography, and preferred extremal property would all represent more or less the same thing. One must of course be very cautious since the boundary conditions at X^3_l involve normal derivative and might bring in delicacies forcing to modify the simplest heuristic picture.

5. There is a possible connection with the notion of self-organized criticality [1] introduced to explain the behavior of systems like sand piles. Self-organization in these systems tends to lead "to the edge". The challenge is to understand how system ends up to a critical state, which by definition is unstable. Mechanisms for this have been discovered and based on phase transitions occurring in a wide range of parameters so that critical point extends to a critical manifold. In TGD Universe quantum criticality suggests a universal mechanism of this kind. The criticality for the preferred extremals of Kähler action would mean that classically all systems are critical in well-defined sense and the question is only about the degree of criticality. Evolution could be seen as a process leading gradually to increasingly critical systems. One must however distinguish between the criticality associated with the preferred extremals of Kähler action and the criticality caused by the spin glass like energy landscape like structure for the space of the maxima of Kähler function.

6.3 Handful of problems with a common resolution

Theory building could be compared to pattern recognition or to a solving a crossword puzzle. It is essential to make trials, even if one is aware that they are probably wrong. When stares long enough to the letters which do not quite fit, one suddenly realizes what one particular crossword must actually be and it is soon clear what those other crosswords are. In the following I describe an example in which this analogy is rather concrete. Let us begin by listing the problems.

1. The condition that modified Dirac action allows conserved charges leads to the condition that the symmetries in question give rise to vanishing second variations of Kähler action. The interpretation is as quantum criticality and there are good arguments suggesting that the critical symmetries define an infinite-dimensional super-conformal algebra forming an inclusion hierarchy related to a sequence of symmetry breakings closely related to a hierarchy of inclusions of hyper-finite factors of types II_1 and III_1. This means an enormous generalization of the symmetry breaking patterns of gauge theories.

   There is however a problem. For the translations of M^4 and color hyper charge and isospin (more generally, any Cartan algebra of $P \times SU(3)$) the resulting fermionic charges vanish. The trial for the crossword in absence of nothing better would be the following argument. By the abelianity of these charges the vanishing of quantal representation of four-momentum and color Cartan charges is not a problem and that classical representation of these charges or their super-conformal representation is enough.

2. Modified Dirac equation is satisfied in the interior of space-time surface always. This means that one does not obtain off-mass shell propagation at all in 4-D sense. Effective 2-dimensionality suggests that off mass shell propagation takes place along wormhole throats. The reduction to almost topological QFT with Kähler function reducing to Chern-Simonst type action implied by the weak form of electric-magnetic duality and a proper gauge choice for the induced Kähler gauge potential implies effective 3-dimensionality at classical level. This inspires the question whether Chern-Simons type action resulting from an instanton term could define the modified

gamma matrices appearing in the 3-D modified Dirac action associated with wormhole throats and the ends of the space-time sheet at the boundaries of CD.

The assumption that modified Dirac equation is satisfied also at the ends and wormhole throats would realize effective 2-dimensionality as conditions on the boundary values of the 4-D Dirac equation but would would not allow off mass shell propagation. Therefore one could argue that effective 2-dimensionality in this sense holds true only for incoming and outgoing particles.

The reduction of Kähler action to Chern-Simons term together with effective 2-dimensionality suggests that Kähler function corresponds to an extremum of this action with a constraint term due to the weak form of electric-magnetic duality. Without this term the extrema of Chern-Simons action have 2-D CP_2 projection not consistent with the weak form of electric-magnetic duality. The extrema are not maxima of Kähler function: they are obtained by varying with respect to tangent space data of the partonic 2-surfaces. Lagrange multiplier term induces also to the modified gamma matrices a contribution which is of the same general form as for any general coordinate invariant action.

3. Quantum classical correspondence requires that the geometry of the space-time sheet should correlate with the quantum numbers characterizing positive (negative) energy part of the quantum state. One could argue that by multiplying WCW spinor field by a suitable phase factor depending on the charges of the state, the correspondence follows from stationary phase approximation. This crossword looks unconvincing. A more precise connection between quantum and classical is required.

4. In quantum measurement theory classical macroscopic variables identified as degrees of freedom assignable to the interior of the space-time sheet correlate with quantum numbers. Stern Gerlach experiment is an excellent example of the situation. The generalization of the imbedding space concept by replacing it with a book like structure implies that imbedding space geometry at given page and for given causal diamond (CD) carries information about the choice of the quantization axes (preferred plane M^2 of M^4 *resp.* geodesic sphere of CP_2 associated with singular covering/factor space of CD *resp.* CP_2). This is a big step but not enough. Modified Dirac action as such does not seem to provide any hint about how to achieve this correspondence. One could even wonder whether dissipative processes or at least the breaking of T and CP characterizing the outcome of quantum jump sequence should have space-time correlate. How to achieve this?

Each of these problems makes one suspect that something is lacking from the modified Dirac action: there should exist an elegant manner to feed information about quantum numbers of the state to the modified Dirac action in turn determining vacuum functional as an exponent Kähler function identified as Kähler action for the preferred extremal assumed to be dictated by by quantum criticality and equivalently by hyper-quaternionicity.

This observation leads to what might be the correct question. Could a general coordinate invariant and Poincare invariant modification of the modified Dirac action consistent with the vacuum degeneracy of Kähler action allow to achieve this information flow somehow? In the following one manner to achieve this modification is discussed. It must be however emphasized that I have considered many alternatives and the one discussed below finds its justification only from the fact that it is the simplest one found hitherto.

6.3.1 The identification of the measurement interaction term

The idea is simple: add to the modified Dirac action a term which is analogous to the Dirac action in $M^4 \times CP_2$. One can consider two options according to whether the term is assigned with interior or with a 3-D light-like 3-surface and last years have been continual argumentation about which option is the correct one.

1. The additional term would be essentially the analog of the ordinary Dirac action at the imbedding space level.

$$\begin{aligned} S_{int} &= \sum_A Q_A \int \overline{\Psi} g^{AB} j_{B\alpha} \hat{\Gamma}^\alpha \Psi \sqrt{g} d^4x \ , \\ g_{AB} &= j_A^k h_{kl} j_B^l \ , \ g^{AB} g_{BC} = \delta_C^A \ , \\ j_{B\alpha} &= j_B^k h_{kl} \partial_\alpha h^l \ . \end{aligned} \tag{6.5}$$

The sum is over isometry charges Q_A interpreted as quantal charges and j^{Ak} denotes the Killing vector field of the isometry. g^{AB} is the inverse of the tensor g_{AB} defined by the local inner products of Killing vectors fields in M^4 and CP_2. The space-time projections of the Killing vector fields $j_{B\alpha}$ have interpretation as classical color gauge potentials in the case of $SU(3)$. In M^4 degrees of freedom and for Cartan algebra of $SU(3)$ $j_{B\alpha}$ reduce to the gradients of linear M^4 coordinates in case of translations. Modified gamma matrices could be assigned to Kähler action or its instanton term or with Chern-Simons action.

2. The added term containing quantal charges must make sense in the modified Dirac equation. This requires that the physical state is an eigenstate of momentum and color charges. This allows only color hyper-charge and color isospin so that there is no hope of obtaining exactly the stringy formula for the propagator. The modified Dirac operator is given by

$$\begin{aligned} D &= D + D_{int} = \hat{\Gamma}^\alpha D_\alpha + \hat{\Gamma}^\alpha \sum_A Q_A g^{AB} j_{B\alpha} \\ &= \hat{\Gamma}^\alpha (D_\alpha + \partial_\alpha \phi) \ , \ \partial_\alpha \phi = \sum_A Q_A g^{AB} j_{B\alpha} \ . \end{aligned} \tag{6.6}$$

The conserved fermionic isometry currents are

$$J^{A\alpha} = \sum_B Q_B \overline{\Psi} g^{BC} j_C^k h_{kl} j_A^l \hat{\Gamma}^\alpha \Psi = Q_A \overline{\Psi} \hat{\Gamma}^\alpha \Psi \ . \tag{6.7}$$

Here the sum is restricted to a Cartan sub-algebra of Poincare group and color group.

3. An important restriction is that by four-dimensionality of M^4 and CP_2 the rank of g_{AB} is 4 so that g^{AB} exists only when one considers only four conserved charges. In the case of M^4 this is achieved by a restriction to translation generators $Q_A = p_A$. g_{AB} reduces to Minkowski metric and Killing vector fields are constants. The Cartan sub-algebra could be however replaced by any four commuting charges in the case of Poincare algebra (second one corresponds to time translation plus translation, boost and rotation in given direction). In the case of $SU(3)$ one must restrict the consideration either to $U(2)$ sub-algebra or its complement. $CP_2 = SU(3)/SU(2)$ decomposition would suggest the complement as the correct choice. One can indeed build the generators of $U(2)$ as commutators of the charges in the complement. On the other hand, Cartan algebra is enough in free field construction of Kac-Moody algebras.

4. What is remarkable that for the Cartan algebra of $M^4 \times SU(3)$ the measurement interaction term is equivalent with the addition of gauge part $\partial_\alpha \phi$ of the induced Kähler gauge potential A_α. This property might hold true for any measurement interaction term. This also suggests that the change in Kähler function is only the transformation $A_\alpha \to A_\alpha + \partial_\alpha \phi$, $\partial_\alpha \phi = \sum_A Q_A g^{AB} j_{B\alpha}$.

5. Recall that the ϕ for $U(1)$ gauge transformations respecting the vanishing of the Coulomb interaction term of Kähler action [12] , [2] the current $j_K^\alpha \phi$ is conserved, which implies that the change of the Kähler action is trivial. These properties characterize the gauge transformations respecting the gauge in which Coulombic interaction term of the Kähler action vanishes so that Kähler action reduces to 3-dimensional generalized Chern-Simons term if the weak form of electric-magnetic duality holds true guaranteeing among other things that the induced Kähler field is not too singular at the wormhole throats [12] , [2] . The scalar function assignable to the measurement interaction terms does not have this property and this is what is expected since it must change the value of the Kähler function and therefore affect the preferred extremal.

Concerning the precise form of the modified Dirac action the basic clue comes from the observation that the measurement interaction term corresponds to the addition of a gauge part to the induced CP_2 Kähler gauge potential A_α. The basic question is what part of the action one assigns the measurement interaction term.

1. One could define the measurement interaction term using either the four-dimensional instanton term or its reduction to Chern-Simons terms. The part of Dirac action defined by the instanton term in the interior does not reduce to a 3-D form unless the Dirac equation defined by the instanton term is satisfied : this cannot be true. Hence Chern-Simons term is the only possibility.

   The classical field equations associated with the Chern-Simons term cannot be assumed since they would imply that the CP_2 projection of the wormhole throat and space-like 3-surface are 2-dimensional. This might hold true for space-like 3-surfaces at the ends of CD and incoming and outgoing particles but not for off mass shell particles. This is however not a problem since $D_\alpha \hat{\Gamma}^\alpha_{C-S}$ for the modified gamma matrices for Chern-Simons action does not contain second derivatives. This is due to the topological character of this term. For Kähler action second derivatives are present and this forces extremal property of Kähler action in the modified Dirac Kähler action so that classical physics results as a consistency condition.

2. If one assigns measurement interaction term to both D_K and D_{C-S} the measurement interaction corresponds to a mere gauge transformation for AS_α and is trivial. Therefore it seems that one must choose between D_K or D_{C-S}. At least formally the measurement interaction term associated with D_K is gauge equivalent with its negative D_{C-S}. The addition of the measurement interaction to D_K changes the basis for the 4-D induced spinors by the phase $exp(-iQK\phi)$ and therefore also the basis for the generalized eigenstates of D_{C-S} and this brings in effectively the measurement interaction term affecting the Dirac determinant.

3. The definition of Dirac determinant should be in terms of Chern-Simons action induced by the instanton term and identified as a product of the generalized eigenvalues of this operator. The modified Dirac equation for Ψ is consistent with that for its conjugate if the coefficient of the instanton term is real and one uses the Dirac action $\overline{\Psi}(D^{\rightarrow} - D^{\leftarrow})\Psi$ giving modified Dirac equation as

$$D_{C-S}\Psi + \frac{1}{2}(D_\alpha \hat{\Gamma}^\alpha_{C-S})\Psi = 0 \ . \qquad (6.8)$$

   As noticed, the divergence of gamma matrices does not contain second derivatives in the case of Chern-Simons action. In the case of Kähler action they occur unless field equations equivalent with the vanishing of the divergence term are satisfied.

   Also the fermionic current is conserved in this case, which conforms with the idea that fermions flow along the light-like 3-surfaces. If one uses the action $\overline{\Psi}D^{\rightarrow}\Psi$, $\overline{\Psi}$ does not satisfy the Dirac equation following from the variational principle and fermion current is not conserved. Also if the Chern-Simons term is imaginary - as a naive idea about dissipation would suggest- the Dirac equation fails to be consistent with the conjugation.

4. Off mass shell states appear in the lines of the generalized Feynman diagrams and for these D_{C-S} cannot annihilate the spinor field. The generalized eigen modes lf D_{C-S} should be such that one obtains the counterpart of Dirac propagator which is purely algebraic and does not therefore depend on the coordinates of the throat. This is satisfied if the generalized eigenvalues are expressible in terms of covariantly constant combinations of gamma matrices and here only M^4 gamma matrices are possible. Therefore the eigenvalue equation reqards as

$$D\Psi = \lambda^k \gamma_k \Psi \ , \ D = D_{C-S} + D_\alpha \hat{\Gamma}^\alpha_{C-S} \ , \ D_{C-S} = \hat{\Gamma}^\alpha_{C-S} D_\alpha \ . \qquad (6.9)$$

   Here the covariant derivatives D_α contain the measurement interaction term as an apparent gauge term. Covariant constancy allows to take the square of this equation and one has

$$(D^2 + \left[D, \lambda^k \gamma_k\right])\Psi + \quad = \quad \lambda^k \lambda_k \Psi \ . \tag{6.10}$$

The commutator term is analogous to magnetic moment interaction. The generalized eigenvalues correspond to $\lambda = \sqrt{\lambda^k \lambda_k}$ and Dirac determinant is defined as a product of the eigenvalues. λ is completely analogous to mass. For incoming lines this mass would vanish so that all incoming particles irrespective their actual quantum numbers would be massless in this sense and the propagator is indeed that for a massless particle. Note that the eigen modes define the boundary values for the solutions of $D_K \Psi = 0$ so that the values of λ indeed define the counterpart of the momentum space.

This transmutation of massive particles to effectively massless ones might make possible the application of the twistor formalism as such in TGD framework [29] . $N = 4$ SUSY is one of the very few gauge theory which might be UV finite but it is definitely unphysical due to the masslessness of the basic quanta. Could the resolution of the interpretational problems be that the four-momenta appearing in this theory do not directly correspond to the observed four-momenta?

6.3.2 Objections

The alert reader has probably raised several critical questions. Doesn't the need to solve λ_k as functions of incoming quantum numbers plus the need to construct the measurement interactions makes the practical application of the theory hopelessly difficult? Could the resulting pseudo-momentum λ_k correspond to the actual four-momentum? Could one drop the measurement interaction term altogether and assume that the quantum classical correspondence is through the identification of the eigenvalues as the four-momenta of the on mass shell particles propagating at the wormhole throats? Could one indeed assume that the momenta have a continuous spectrum and thus do not depend on the boundary conditions at all? Usually the thinking is just the opposite and in the general case would lead to to singular eigen modes.

1. Only the information about four-momentum would be fed into the space-time geometry. TGD however allows much more general measurement interaction terms and it would be very strange if the space-time geometry would not correlate also with the other quantum numbers. Mass formulas would of course contain information also about other quantum numbers so that this claim is not quite justified.

2. Number theoretic considerations and also the construction of octonionic variant of Dirac equation [25] , [4] force the conclusion that the spectrum of pseudo four-momentum is restricted to a preferred plane M^2 of M^4 and this excludes the interpretation of λ^k as a genuine four-momentum. It also improves the hopes that the sum over pseudo-momenta does not imply divergences.

3. Dirac determinant would depend on the mass spectrum only and could not be identified as exponent of Kähler function. Note that the original guideline was the dream about stringy propagators. This is achieved for $\lambda_A \lambda^A = n$ in suitable units. This spectrum would of course also imply that Dirac determinant defined in terms of ζ function regularization is independent of the space-time surface and could not be identified with the exponent of Kähler function. One must of course take the identification of exponent of Kähler function as Dirac determinant as an additional conjecture which is not necessary for the calculation of Kähler function if the weak form of electric-magnetic duality is accepted.

4. All particles would behave as massless particles and this would not be consistent with the proposed Feynman diagrammatics inspired by zero energy ontology. Since wormhole throats carry on mass shell particles with positive or negative energy so that the net momentum can be also space-like propagators diverge for massless particles. One might overcome this problem by assuming small thermal mass (from p-adic thermodynamics [19]) and this is indeed assumed to reduce the number of generalized Feynman diagrams contributing to a given reaction to finite number.

Second objection of the skeptic reader relates to the delicacies of $U(1)$ gauge invariance. The modified Dirac action seems to break gauge symmetries and this breaking of gauge symmetry is absolutely essential for the dependence of the Dirac determinant on the quantum numbers. It however seems that this breaking of gauge invariance is only apparent.

1. One must distinguish between genuine $U(1)$ gauge transformations carried out for the induced Kähler gauge potential A_α and apparent gauge transformations of the Kähler gauge potential A_k of $S^2 \times CP_2$ induced by symplectic transformations deforming the space-time surface and affect also induced metric. This delicacy of $U(1)$ gauge symmetry explains also the apparent breaking of $U(1)$ gauge symmetry of Chern-Simons Dirac action due to the presence of explicit terms A_k and A_α.

2. CP_2 Kähler gauge potential is obtained in complex coordinates from Kähler function as $(K_{\xi^i}, K_{\overline{\xi^i}}) = (\partial_{\xi^i}K, -\partial_{\overline{\xi^i}}K)$. Gauge transformations correspond to the additions $K \rightarrow K + f + \overline{f}$, where f is a holomorphic function. Kähler gauge potential has a unique gauge in which the Kähler function of CP_2 is $U(2)$ invariant and contains no holomorphic part. Hence A_k is defined in a preferred gauge and is a gauge invariant quantity in this sense. Same applies to S^2 part of the Kähler potential if present.

3. A_α should be also gauge invariant under gauge transformation respecting the vanishing of Coulombic interaction energy. The allowed gauge transformations $A_\alpha \rightarrow A_\alpha + \partial_\alpha \phi$ must satisfy $D_\alpha(j_K^\alpha \phi) = 0$. If the scalar function ϕ reduces to constant at the wormhole throats and at the ends of the space-time surface D_{C-S} is gauge invariant. The gauge transformations for which ϕ does not satisfy this condition are identified as representations of critical deformations of space-time surface so that the change of A_α would code for this kind of deformation and indeed affect the modified Dirac operator and Kähler function (the change would be due to the change of zero modes).

6.3.3 Some details about the modified Dirac equation defined by Chern-Simons action

First some general comments about D_{C-S} are in order.

1. Quite generally, there is vacuum avoidance in the sense that Ψ must vanish in the regions where the modified gamma matrices vanish. A physical analogy for the system consider is a charged particle in an external magnetic field. The effective metric defined by the anti-commutators of the modified gamma matrices so that standard intuitions might not help much. What one would naively expect would be analogs of bound states in magnetic field localized into regions inside which the magnetic field is non-vanishing.

2. If only CP_2 Kähler form appears in the Kähler action, the modified Dirac action defined by the Chern-Simons term is non-vanishing only when the dimension of the CP_2 projection of the 3-surface is $D(CP_2) \geq 2$ and the induced Kähler field is non-vanishing. This conforms with the properties of Kähler action. The solutions of the modified Dirac equation with a vanishing eigenvalue λ would naturally correspond to incoming and outgoing particles.

3. $D(CP_2) \leq 2$ is apparently inconsistent with the weak form of electric-magnetic duality requiring $D(CP_2) = 3$. The conclusion is wrong: the variations of Chern-Simons action are subject to the constraint that electric-magnetic duality holds true expressible in terms of Lagrange multiplier term

$$\int \Lambda_\alpha (J^{n\alpha} - K\epsilon^{n\alpha\beta\gamma} J_{\beta\gamma})\sqrt{g_4} d^3x \quad . \tag{6.11}$$

   This gives a constraint force to the field equations and also a dependence on the induced 4-metric so that one has only almost topological QFT. This term also guarantees the M^4 part of WCW Kähler metric is non-trivial. The condition that the ends of space-time sheet and wormhole throats are extrema of Chern-Simons action subject to the electric-magnetic duality constraint is strongly suggested by the effective 2-dimensionality.

4. Electric-magnetic duality constraint gives an additional term to the Dirac action determined by the Lagrange multiplier term. This term gives an additional contribution to the modified gamma matrices having the same general form as coming from Kähler action and Chern-Simons action. In the following this term will not be considered. For the extremals it only affects the modified gamma matrices and leaves the general form of solutions unchanged.

In absence of the constraint from the weak form of electric-magnetic duality the explicit expression of D_{C-S} is given by

$$\begin{aligned} D &= \hat{\Gamma}^{\mu} D_{\mu} + \frac{1}{2} D_{\mu} \hat{\Gamma}^{\mu} \ , \\ \hat{\Gamma}^{\mu} &= \frac{\partial L_{C-S}}{\partial_{\mu} h^k} \Gamma_k = \epsilon^{\mu\alpha\beta} \left[2 J_{kl} \partial_{\alpha} h^l A_{\beta} + J_{\alpha\beta} A_k \right] \Gamma^k D_{\mu} \ , \\ D_{\mu} \hat{\Gamma}^{\mu} &= B^{\alpha}_K (J_{k\alpha} + \partial_{\alpha} A_k) \ , \\ B^{\alpha}_K &= \epsilon^{\alpha\beta\gamma} J_{\beta\gamma} \ , \ J_{k\alpha} = J_{kl} \partial_{\alpha} s^l \ , \ \hat{\epsilon}^{\alpha\beta\gamma} = \epsilon^{\alpha\beta\gamma} \sqrt{g_3} \ . \end{aligned} \tag{6.12}$$

Note $\hat{\epsilon}^{\alpha\beta\gamma} =$ does not depend on the induced metric.

The extremals of Chern-Simons action without constraint term satisfy

$$B^{\alpha}_K (J_{kl} + \partial_l A_k) \partial_{\alpha} h^l = 0 \ , \ B^{\alpha}_K = \epsilon^{\alpha\beta\gamma} J_{\beta\gamma} \ . \tag{6.13}$$

For a non-vanishing Kähler magnetic field B^{α} these equations hold true when CP_2 projection is 2-dimensional. This implies a vanishing of Chern-Simons action in absence of the constraint term realizing electric-magnetic duality, which is therefore absolutely essential in order for having a non-vanishing WCW metric.

Consider now the situation in more detail.

1. Suppose that one can assign a global coordinate to the flow lines of the Kähler magnetic field. In this case one might hope that ordinary intuitions about motion in constant magnetic field might be helpful. The repetition of the discussion of [12] , [2] leads to the condition $B \wedge dB = 0$ implying that a Beltrami flow for which current flows along the field lines and Lorentz forces vanishes is in question. This need not be the generic case.

2. With this assumption the modified Dirac operator reduces to a one-dimensional Dirac operator

$$D = \hat{\epsilon}^{r\alpha\beta} \left[2 J_{kl} \partial_{\alpha} h^l A_{\beta} + J_{\alpha\beta} A_k \right] \Gamma^k D_r \ . \tag{6.14}$$

3. The general solutions of the modified Dirac equation is covariantly constant with respect to the coordinate r:

$$D_r \Psi = 0 \ . \tag{6.15}$$

The solution to this condition can be written immediately in terms of a non-integrable phase factor $Pexp(i \int A_r dr)$, where integration is along curve with constant transversal coordinates. If $\hat{\Gamma^v}$ is light-like vector field also $\hat{\Gamma^v} \Psi_0$ defines a solution of D_{C-S}. This solution corresponds to a zero mode for D_{C-S} and does not contribute to the Dirac determinant. Note that the dependence of these solutions on transversal coordinates of X^3_l is arbitrary.

4. The formal solution associated with a general eigenvalue can be constructed by integrating the eigenvalue equation separately along all coordinate curves. This makes sense if r indeed assigned to light-like curves indeed defines a global coordinate. What is strange that there is no correlation between the behaviors with respect longitudinal coordinate and transversal coordinates. System would be like a collection of totally uncorrelated point like particles reflecting the flow of the current along flux lines. It is difficult to say anything about the spectrum of the generalized eigenvalues in this case: it might be that the boundary conditions at the ends of the flow lines fix the allowed values of λ. Clearly, the Beltrami flow property is what makes this case very special.

6.3.4 A connection with quantum measurement theory

It is encouraging that isometry charges and also other charges could make themselves visible in the geometry of space-time surface as they should by quantum classical correspondence. This suggests an interpretation in terms of quantum measurement theory.

1. The interpretation resolves the problem caused by the fact that the choice of the commuting isometry charges is not unique. Cartan algebra corresponds naturally to the measured observables. For instance, one could choose the Cartan algebra of Poincare group to consist of energy and momentum, angular momentum and boost (velocity) in particular direction as generators of the Cartan algebra of Poincare group. In fact, the choices of a preferred plane $M^2 \subset M^4$ and geodesic sphere $S^2 \subset CP_2$ allowing to fix the measurement sub-algebra to a high degree are implied by the replacement of the imbedding space with a book like structure forced by the hierarchy of Planck constants. Therefore the hierarchy of Planck constants seems to be required by quantum measurement theory. One cannot overemphasize the importance of this connection.

2. One can add similar couplings of the net values of the measured observables to the currents whose existence and conservation is guaranteed by quantum criticality. It is essential that one maps the observables to Cartan algebra coupled to critical current characterizing the observable in question. The coupling should have interpretation as a replacement of the induced Kähler gauge potential with its gauge transform. Quantum classical correspondence encourages the identification of the classical charges associated with Kähler action with quantal Cartan charges. This would support the interpretation in terms of a measurement interaction feeding information to classical space-time physics about the eigenvalues of the observables of the measured system. The resulting field equations remain second order partial differential equations since the second order partial derivatives appear only linearly in the added terms.

3. What about the space-time correlates of electro-weak charges? The earlier proposal explains this correlation in terms of the properties of quantum states: the coupling of electro-weak charges to Chern-Simons term could give the correlation in stationary phase approximation. It would be however very strange if the coupling of electro-weak charges with the geometry of the space-time sheet would not have the same universal description based on quantum measurement theory as isometry charges have.

   (a) The hint as how this description could be achieved comes from a long standing un-answered question motivated by the fact that electro-weak gauge group identifiable as the holonomy group of CP_2 can be identified as $U(2)$ subgroup of color group. Could the electro-weak charges be identified as classical color charges? This might make sense since the color charges have also identification as fermionic charges implied by quantum criticality. Or could electro-weak charges be only represented as classical color charges by mapping them to classical color currents in the measurement interaction term in the modified Dirac action? At least this question might make sense.

   (b) It does not make sense to couple both electro-weak and color charges to the same fermion current. There are also other fundamental fermion currents which are conserved. All the following currents are conserved.

$$\begin{array}{rcl} J^\alpha & = & \overline{\Psi} O \hat{\Gamma}^\alpha \Psi \\ O & \in & \{1 \ , \ J \equiv J_{kl}\Sigma^{kl} \ , \ \Sigma_{AB} \ , \ \Sigma_{AB} J\} \ . \end{array} \qquad (6.16)$$

   Here J_{kl} is the covariantly constant CP_2 Kähler form and Σ_{AB} is the (also covariantly) constant sigma matrix of M^4 (flatness is absolutely essential).

   (c) Electromagnetic charge can be expressed as a linear combination of currents corresponding to $O = 1$ and $O = J$ and vectorial isospin current corresponds to J. It is natural to couple of electromagnetic charge to the the projection of Killing vector field of color hyper charge and coupling it to the current defined by $O_{em} = a+bJ$. This allows to interpret the puzzling finding that electromagnetic charge can be identified as anomalous color hyper-charge for induced spinor fields made already during the first years of TGD. There exist no conserved axial isospin currents in accordance with CVC and PCAC hypothesis which belong to the basic stuff of the hadron physics of old days.

(d) Color charges would couple naturally to lepton and quark number current and the $U(1)$ part of electro-weak charges to the $n = 1$ multiple of quark current and $n = 3$ multiple of the lepton current (note that leptons *resp.* quarks correspond to $t = 0$ *resp.* $t = \pm 1$ color partial waves). If electro-weak *resp.* couplings to H-chirality are proportional to 1 *resp.* Γ_9, the fermionic currents assigned to color and electro-weak charges can be regarded as independent. This explains why the possibility of both vectorial and axial couplings in 8-D sense does not imply the doubling of gauge bosons.

(e) There is also an infinite variety of conserved currents obtained as the quantum critical deformations of the basic fermion currents identified above. This would allow in principle to couple an arbitrary number of observables to the geometry of the space-time sheet by mapping them to Cartan algebras of Poincare and color group for a particular conserved quantum critical current. Quantum criticality would therefore make possible classical space-time correlates of observables necessary for quantum measurement theory.

(f) The coupling constants associated with the deformations would appear in the couplings. Quantum criticality ($K \rightarrow K + f + \overline{f}$ condition) should predict the spectrum of these couplings. In the case of momentum the coupling would be proportional to $\sqrt{G/\hbar_0} = kR/\hbar_0$ and $k \sim 2^{11}$ should follow from quantum criticality. p-Adic coupling constant evolution should follow from the dependence on the scale of CD coming as powers of 2.

4. Quantum criticality implies fluctuations in long length and time scales and it is not surprising that quantum criticality is needed to produce a correlation between quantal degrees of freedom and macroscopic degrees of freedom. Note that quantum classical correspondence can be regarded as an abstract form of entanglement induced by the entanglement between quantum charges Q_A and fermion number type charges assignable to zero modes.

5. Space-time sheets can have an arbitrary number of wormhole contacts so that the interpretation in terms of measurement theory coupling short and long length scales suggests that the measurement interaction terms are localizable at the wormhole throats. This would favor Chern-Simons term or possibly instanton term if reducible to Chern-Simons terms. The breaking of CP and T might relate to the fact that state function reductions performed in quantum measurements indeed induce dissipation and breaking of time reversal invariance.

6. The experimental arrangement quite concretely splits the quantum state to a quantum superposition of space-time sheets such that each eigenstate of the measured observables in the superposition corresponds to different space-time sheet already before the realization of state function reduction. This relates interestingly to the question whether state function reduction really occurs or whether only a branching of wave function defined by WCW spinor field takes place as in multiverse interpretation in which different branches correspond to different observers. TGD inspired theory consciousness requires that state function reduction takes place. Maybe multiversalist might be able to find from this picture support for his own beliefs.

7. One can argue that "free will" appears not only at the level of quantum jumps but also as the possibility to select the observables appearing in the modified Dirac action dictating in turn the Kähler function defining the Kähler metric of WCW representing the "laws of physics". This need not to be the case. The choice of CD fixes M^2 and the geodesic sphere S^2: this does not fix completely the choice of the quantization axis but by isometry invariance rotations and color rotations do not affect Kähler function for given CD and for a given type of Cartan algebra. In M^4 degrees of freedom the possibility to select the observables in two manners corresponding to linear and cylindrical Minkowski coordinates could imply that the resulting Kähler functions are different. The corresponding Kähler metrics do not differ if the real parts of the Kähler functions associated with the two choices differ by a term $f(Z) + \overline{f(Z)}$, where Z denotes complex coordinates of WCW, the Kähler metric remains the same. The function f can depend also on zero modes. If this is the case then one can allow in given CD superpositions of WCW spinor fields for which the measurement interactions are different. This condition is expected to pose non-trivial constraints on the measurement action and quantize coupling parameters appearing in it.

6.3.5 New view about gravitational mass and matter antimatter asymmetry

The physical interpretation of the additional term in the modified Dirac action might force quite a radical revision of the ideas about matter and antimatter.

1. The term $p_A\partial_\alpha m^A$ contracted with the fermion current is analogous to a gauge potential coupling to fermion number. Since the additional terms in the modified Dirac operator induce stringy propagation, a natural interpretation of the coupling to the induced spinor fields is in terms of gravitation. One might perhaps say that the measurement of four momentum induces gravitational interaction. Besides momentum components also color charges take the role of gravitational charges. As a matter fact, any observable takes this role via coupling to the projections of Killing vector fields of Cartan algebra. The analogy of color interactions with gravitational interactions is indeed one of the oldest ideas in TGD.

2. The coupling to four-momentum is through fermion number (both quark number and lepton number). For states with a vanishing fermion number isometry charges therefore vanish. In this framework matter antimatter asymmetry would be due to the fact that matter (antimatter) corresponds to positive (negative) energy parts of zero energy states for massive systems so that the contributions to the net gravitational four-momentum are of same sign. Could antimatter be unobservable to us because it resides at negative energy space-time sheets? As a matter fact, I proposed already years ago that gravitational mass is essentially the magnitude of the inertial mass but gave up this idea.

3. Bosons do not couple at all to gravitation if they are purely local bound states of fermion and anti-fermion at the same space-time sheet (say represented by generators of super Kac-Moody algebra). Therefore the only possible identification of gauge bosons is as wormhole contacts. If the fermion and anti-fermion at the opposite throats of the contact correspond to positive and negative energy states the net gravitational energy receives a positive contribution from both sheets. If both correspond to positive (negative) energy the contributions to the net four-momentum have opposite signs. It is not yet clear which identification is the correct one.

6.4 Generalized eigenvalues of D_{C-S} and General Coordinate Invariance

The fixing of light-like 3-surface to be the wormhole throat at which the signature of induced metric changes from Minkowskian to Euclidian corresponds to a convenient fixing of gauge. General Coordinate Invariance however requires that any light-like surface Y_l^3 parallel to X_l^3 in the slicing is equally good choice. In particular, it should give rise to same Kähler metric but not necessarily the same exponent of Kähler function identified as the product of the generalized eigenvalues of $D_{C,S}$ at Y_l^3.

General Coordinate Invariance requires that the components of Kähler metric of configuration space defined in terms of Kähler function as

$$G_{k\bar{l}} = \partial_k\partial_{\bar{l}}K = \sum_i \partial_k\partial_{\bar{l}}\lambda_i$$

remain invariant under this flow. Here complex coordinate are of course associated with the configuration space. This is the case if the flow corresponds to the addition of sum of holomorphic function $f(z)$ and its conjugate $\overline{f}(z))$ which is anti-holomorphic function to K. This boils down to the scaling of eigenvalues λ_i by

$$\lambda_i \rightarrow exp(f_i(z) + \overline{f_i(z)})\lambda_i \quad . \tag{6.17}$$

If the eigenvalues are interpreted as vacuum conformal weights, general coordinate transformations correspond to a spectral flow scaling the eigenvalues in this manner. This in turn would induce spectral flow of ground state conformal weights if the squares of λ_i correspond to ground state conformal weights.

7 Representations for the configuration space gamma matrices in terms of super-symplectic charges at light cone boundary

During years I have considered several variants for the representation of WCW gamma matrices and each of these proposals has had some weakness.

1. One question has been whether the Noether currents assignable to WCW Hamiltonians should play any role in the construction or whether one can use only the generalization of flux Hamiltonians. Magnetic flux Hamiltonians do not refer to the space-time dynamics implying genuine 2-dimensionality, which is a catastrophe. If the sum of the magnetic and electric flux Hamiltonians and the weak form of self duality is assumed effective 2-dimensionality is achieved. The challenge is to identify the super-partners of the flux Hamiltonians and postulate correct anti-commutation relations for the induced spinor fields to achieve anti-commutation to flux Hamiltonians.

2. In the original proposal for WCW gamma matrices the covariantly constant right handed spinors played a key role. This led to interpretational problems with quarks. Are they needed at all or do leptons and quarks define somehow equivalent representations? I discovered only recently a brutally simple but deadly objection against this approach: the resulting WCW gamma matrices do not generate all WCW spinors from Fock vacuum. Therefore all modes of the induced spinor fields must be used.

The latter objection forced to realize that nothing is changed if one replaces the covariantly constant right handed neutrino with the collection of quark spinor modes q_n *resp.* leptonic spinor modes L_n multiplied by the contractions $J_{A+} = j^{Ak}\Gamma_k$ *resp.* its conjugate $J_{A-} = j^{A\bar{k}}\Gamma_{\overline{k}}$. It is essential that only of these contractions is used for a given H-chirality.

1. If the anti-commutator of the spinor fields is or form $J = J_{\alpha\beta}\epsilon^{\alpha\beta}\delta^2(x,y)$ at X^2 for magnetic flux Hamiltonians and appropriate generalization of this fro the sum of magnetic and electric flux Hamiltonians, the "half-Poisson bracket" $\partial_k H_A J^{k\bar{l}}\partial_{\bar{l}} H_B$ from the quark spinor field and its conjugate as anti-commutator from the leptonic spinor field can combine to the full Poisson bracket if the remaining factors are identical.

2. This happens if the quark modes and lepton-like modes are in 1-1 correspondence and the contractions of the eigenmodes resulting in the contraction satisfy $\overline{q}_m\gamma^0 q_n = \overline{L}_m\gamma^0 L_n = \Phi_{mn}$. The resulting Hamiltonians define an X^2-local algebra: that this extension is needed became obvious already earlier. A stronger condition is that the spinors can be expressed in terms of scalar function bases $\{\Phi_m\}$ so that one would have $q_{m,i} = \{\Phi_m\}q_i$ and $L_{m,i} = \{\Phi_m\}L_i$ so that one would assign to the super-currents the local Hamiltonians $\Phi_m H_A$.

3. One could of course still argue that it is questionable to use sum of quark and lepton gamma matrices since this the resulting objects to not have a well defined fermion number and cannot be used to generate physical states from vacuum. How seriously this argument should be taken is not clear to me at this moment. One could of course consider also a scenario in which one divides leptonic (or quark) modes to two classes analogous to quark and lepton modes and uses J_{A_+} *resp.* J_{A_-} for these two classes.

In any case, the recent view is that all modes of the induced spinor fields must be used, that lepton-quark degeneracy is absolutely essential for the construction of WCW geometry, and that the original super-symmetrization of the flux Hamiltonians combined with weak electric-magnetic duality is the correct approach. There are also fermionic Noether charges and their super counterparts implied by the criticality but these can be assigned with zero modes.

This section represents both the earlier version of the construction of configuration gamma matrices and the construction introducing explicitly the notion of finite measurement resolution. The motivation for the latter option is that if the number the generalized eigen modes of modified Dirac operator is finite, strictly local anti-commutation relations fail unless one restricts the set of points included to that corresponding to number theoretic braid. In the following integral expressions for configuration space Hamiltonians and their super-counterparts are derived first. After that the motivations for replacing integrals with sums are discussed and the expressions for Hamiltonians and super Hamiltonians are derived.

7.1 Magnetic flux representation of the super-symplectic algebra

In order to derive representation of the configuration space gamma matrices and super charges it is good to restate the basic facts about the magnetic flux representation of the configuration space gamma matrices using the original approach based on 2-dimensional integrals.

7.2 Quantization of the modified Dirac action and configuration space geometry

The quantization of the modified Dirac action involves a fusion of various number theoretical ideas. The naive approach would be based on standard canonical quantization of induced spinor fields by posing anti-commutation relations between Ψ and canonical momentum density $\partial L/\partial(\partial_t\Psi)$.

7.2.1 Generalized magnetic and electric fluxes

Isometry invariants are just a special case of fluxes defining natural coordinate variables for the configuration space. Canonical transformations of CP_2 act as $U(1)$ gauge transformations on the Kähler potential of CP_2 (similar conclusion holds at the level of $\delta M^4_+ \times CP_2$).

One can generalize these transformations to local symplectic transformations by allowing the Hamiltonians to be products of the CP_2 Hamiltonians with the real and imaginary parts of the functions $f_{s,n,k}$ defining the Lorentz covariant function basis H_A, $A \equiv (a,s,n,k)$ at the light cone boundary: $H_A = H_a \times f(s,n,k)$, where a labels the Hamiltonians of CP_2.

One can associate to any Hamiltonian H^A of this kind magnetic or electric flux via the following formulas:

$$Q_{m/e}(H_A|X^2) \quad = \quad \int_{X^2} H_A J_{m/e} \quad . \tag{7.1}$$

Here the magnetic (electric) flux J_m (J_e) denotes the flux associated with induced Kähler field and its dual which is well-defined since X^2 is part of 4-D space-time surface.

The flux Hamiltonians

$$Q_i(H_A|X^2) \quad = \quad Q_i(H_A|X^2) \ , \ \ A \equiv (a,s,n,k) \tag{7.2}$$

provide a representation of WCW Hamiltonians as far as the "kinetic" part of Kähler form is considered.

7.2.2 Anti-commutation relations between oscillator operators associated with same partonic 2-surface

The construction of WCW gamma matrices leads to the anti-commutation relations given by

$$\begin{aligned} \{\overline{\Psi}(x)\gamma^0, \Psi(x)\} &= [J_e + J_m)\delta^2_{x,y} \ , \\ J_e &= \int J^{03}\sqrt{g_4} \ . \end{aligned} \tag{7.3}$$

Kähler magnetic flux $J_m = \epsilon^{\alpha\beta} J_{\alpha\beta}\sqrt{g_2}$ has no dependence on the induced metric.

If the weak- form of the electric-magnetic duality holds true, Kähler electric flux relates to it via the formula

$$J^{03}\sqrt{g_4} = KJ_{12} \ \ ,$$

where K is symplectic invariant and identifiable in terms of Kähler coupling strength from classical charge quantization condition for Kähler electric flux. The condition that the flux of $F^{03} = (\hbar/g_K)J^{03}$ defining the counterpart of Kähler electric field equals to the Kähler charge g_K gives the condition $K = g_K^2/\hbar = 4\pi\alpha_K$, where g_K is Kähler coupling constant. Within experimental uncertainties one has $\alpha_K = g_K^2/4\pi\hbar_0 = \alpha_{em} \simeq 1/137$, where α_{em} is finite structure constant in electron length scale and $\hbar_0$ is the standard value of Planck constant. The arguments leading to the identification $\epsilon \pm 1$ at the opposite boundaries of CD are discussed in [12] , [2] . An alternative identification is as $\epsilon = 0$ but predicts that WCW is trivial in M^4 degrees of freedom if Kähler function reduces to Chern-Simons terms.

The general form of the anti-commutation relations is therefore

$$\{\overline{\Psi}(x)\gamma^0, \Psi(x)\} = (1+K)J\delta^2_{x,y} \ . \tag{7.4}$$

What is nice that at the limit of vacuum extremals the right hand side vanishes when both J and J^1 vanish so that spinor fields become non-dynamical. One can criticize the non-vanishing of the anti-commutator for vacuum extremals of Kähler action.

For the latter option the fermionic counterparts of local flux Hamiltonians can be written in the form

$$\begin{aligned}
H_{A,\pm,n} &= \epsilon_q(A,\mp,n)H_{A,\pm,q,n} + \epsilon_L(A,\pm)H_{A,\mp,L,n} \ , \\
H_{A,+,q,n} &= \oint \overline{\Psi} J_+^A q_n d^2x \ , \\
H_{A,-,q,n} &= \oint \overline{q}_n J_-^A \Psi d^2x \ , \\
H_{A,-,L,n} &= \oint \overline{\Psi} J_+^A L_n d^2x \ , \\
H_{A,+,L,n} &= \oint \overline{L}_n J_-^A \Psi d^2x \ , \\
J_+^A &= j^{Ak}\Gamma_k \ , \ J_-^A = j^{A\overline{k}}\Gamma_{\overline{k}} \ .
\end{aligned} \tag{7.5}$$

The commutative parameters $\epsilon_q(A,\pm,n)$ *resp.* $\epsilon_L(A,\pm,n)$ are assumed to carry quark *resp.* lepton number opposite to that of $H_{A,\mp,q,n}$ *resp.* $H_{A,\mp,L,n}$ and satisfy $\epsilon_i(A,+,n)\epsilon_i(A,-,n) = 1$. One encounters a hierarchy discrete algebras satisfying this condition in the construction of a symplectic analog of conformal quantum field theory required by the construction of quantum TGD [22] . Associativity condition fixes uniquely the commutative multiplication of these units and analogs of plane waves with discrete momentum are in question.

Suppose that there is a one-one correspondence between quark modes and leptonic modes is satisfied and the label n decomposes as $n = (m,i)$, where n labels a scalar function basis and i labels spinor components. This would give

$$\begin{aligned}
q_n = q_{m,i} &= \Phi_m q_i \ , \\
L_n = L_{m,i} &= \Phi_m L_i \ , \\
\overline{q}_i\gamma^0 q_j &= \overline{L}_i\gamma^0 L_j = g_{ij} \ .
\end{aligned} \tag{7.6}$$

Suppose that the inner products g_{ij} are constant. The simplest possibility is $g_{ij} = \delta_{ij}$ Under these assumptions the anti-commutators of the super-symmetric flux Hamiltonians give flux Hamiltonians.

$$\{H_{A,+,n}, H_{A,-,n}\} = g_{ij} \oint \overline{\Phi}_m \Phi_n H_A J d^2x \ . \tag{7.7}$$

The product of scalar functions can be expressed as

$$\overline{\Phi}_m \Phi_n = c_{mn}^{\ \ k}\Phi_k \ . \tag{7.8}$$

Note that the notion of symplectic QFT [6] led to a scalar function algebra of similar kind consisting of phase factors and there excellent reasons to consider the possibility that there is a deep connection with this approach.

One expects that the symplectic algebra is restricted to a direct sum of symplectic algebras localized to the regions where the induced Kähler form is non-vanishing implying that the algebras associated with different region form to a direct sum. Also the contributions to configuration space metric are direct sums. The symplectic algebras associated with different region can be truncated to finite-dimensional spaces of symplectic algebras associated with the regions in question. As far as coordinatization of the reduced configuration space is considered, these symplectic sub-spaces are enough. These truncated algebras naturally correspond to the hyper-finite factor property of the Clifford algebra of configuration space.

7.2.3 Generalization of WCW Hamiltonians and anti-commutation relations between flux Hamiltonians belonging to different ends of CD

This picture requires a generalization of the view about configuration space Hamiltonians since also the interaction term between the ends of the line is present not taken into account in the previous approach.

1. The proposed representation of WCW Hamiltonians as flux Hamiltonians [5, 4] , [3]

$$Q(H_A) \quad = \quad \int H_A J d^2x \ . \tag{7.9}$$

works for the kinetic terms only since J is not expectred to be the same at the ends of the line.

The assumption that Poisson bracket of WCW Hamiltonians reduces to the level of imbedding space - in other words $\{Q(H_A), Q(H_B\} = Q(\{H_A, H_B\})$ - can be justified. One starts from the representation in terms of say flux Hamiltonians $Q(H_A)$ and *defines* $J_{A,B}$ as $J_{A,B} \equiv Q(\{H_A, H_B\})$. One has $\partial H_A/\partial t_B = \{H_B, H_A\}$, where t_B is the parameter associated with the exponentiation of H_B. The inverse J^{AB} of $J_{A,B} = \partial H_B/\partial t_A$ is expressible as $J^{A,B} = \partial t_A/\partial H_B$. From these formulas one can deduce by using chain rule that the bracket $\{Q(H_A), Q(H_B\} = \partial t_C Q(H_A) J^{CD} \partial t_D Q(H_B)$ of flux Hamiltonians equals to the flux Hamiltonian $Q(\{H_A, H_B\})$.

2. One should be able to assign to WCW Hamiltonians also a part corresponding to the interaction term. The symplectic conjugation associated with the interaction term permutes the WCW coordinates assignable to the ends of the line. One should reduce this apparently non-local symplectic conjugation (if one thinks the ends of line as separate objects) to a non-local symplectic conjugation for $\delta CD \times CP_2$ by identifying the points of lower and upper end of CD related by time reflection and assuming that conjugation corresponds to time reflection. Formally this gives a well defined generalization of the local Poisson brackets between time reflected points at the boundaries of CD. The connection of Hermitian conjugation and time reflection in quantum field theories is is in accordance with this picture.

3. Perhaps the only manner to proceed is to assign to the flux Hamiltonian also a part obtained by the replacement of the flux integral over X^2 with an integral over the projection of X^2 to a sphere S^2 assignable to the light-cone boundary or to a geodesic sphere of CP_2, which come as two varieties corresponding to homologically trivial and non-trivial spheres. The projection is defined as by the geodesic line orthogonal to S^2 and going through the point of X^2. The hierarchy of Planck constants assigns to CD a preferred geodesic sphere of CP_2 as well as a unique sphere S^2 as a sphere for which the radial coordinate r_M or the light-cone boundary defined uniquely is constant: this radial coordinate corresponds to spherical coordinate in the rest system defined by the time-like vector connecting the tips of CD. Either spheres or possibly both of them could be relevant.

Recall that also the construction of number theoretic braids and symplectic QFT [6] led to the proposal that braid diagrams and symplectic triangulations could be defined in terms of projections of braid strands to one of these spheres. One could also consider a weakening for the condition that the points of the number theoretic braid are algebraic by requiring only that the S^2 coordinates of the projection are algebraic and that these coordinates correspond to the discretization of S^2 in terms of the phase angles associated with θ and ϕ.

This gives for the corresponding contribution of the WCW Hamiltonian the expression

$$Q(H_A)_{int} = (1+K)\int_{S^2_\pm} H_A X\delta^2(s_+,s_-)d^2s_\pm = (1+K)\int_{P(X^2_+)\cap P(X^2_-)} \frac{\partial(s^1,s^2)}{\partial(x^1_\pm,x^2_\pm)}d^2x . \quad (7.10)$$

Here the Poisson brackets between ends of the line using the rules involve delta function $\delta^2(s_+,s_-)$ at S^2 and the resulting Hamiltonians can be expressed as a similar integral of $H_{[A,B]}$ over the upper or lower end since the integral is over the intersection of S^2 projections.

The expression must vanish when the induced Kähler form vanishes for either end. This is achieved by identifying the scalar X in the following manner:

$$\begin{aligned} X &= J^+_{kl} + J^-_{kl} \ , \\ J^{kl}_\pm &= \partial_\alpha s^k \partial_\beta s^l J^{\alpha\beta}_\pm \ . \end{aligned} \quad (7.11)$$

The tensors are lifts of the induced Kähler form of $X^2_\pm$ to S^2 (not CP_2).

4. One could of course ask why these Hamiltonians could not contribute also to the kinetic terms and why the brackets with flux Hamiltonians should vanish. This relate to how one *defines* the Kähler form. It was shown above that in case of flux Hamiltonians the definition of Kähler form as brackets gives the basic formula $\{Q(H_A),Q(H_B)\} = Q(\{H_A,H_B\}$ and same should hold true now. In the recent case $J_{A,B}$ would contain an interaction term defined in terms of flux Hamiltonians and the previous argument should go through also now by identifying Hamiltonians as sums of two contributions and by introducing the doubling of the coordinates t_A.

5. The quantization of the modified Dirac operator must be reconsidered. It would seem that one must add to the super-Hamiltonian completely analogous term obtained by replacing J with $X\partial(s^1,s^2)/\partial(x^1_\pm,x^2_\pm)$. Besides the anti-commutation relations defining correct anti-commutators to flux Hamiltonians, one should pose anti-commutation relations consistent with the anti-commutation relations of super Hamiltonians. In these anti-commutation relations $J\delta^2(x,y)$ would be replaced with $X\delta^2(s^+,s^-)$. This would guarantee that the oscillator operators at the ends of the line are not independent and that the resulting Hamiltonian reduces to integral over either end for $H_{[A,B]}$.

7.3 Expressions for configuration space super-symplectic generators in finite measurement resolution

The expressions of configuration space Hamiltonians and their super counterparts just discussed were based on 2-dimensional integrals. This is problematic for several reasons.

1. In p-adic context integrals do not makes sense so that this representation fails in p-adic context (for pe-adic numbers see [9]). Sums would be more appropriate if one wants number theoretic universality at the level of basic formulas.

2. The use of sums would also conform with the notion of finite measurement resolution having discretization in terms of intersections of X^2 with number theoretic braids as a space-time correlate.

3. Number theoretic duality suggests a unique realization of the discretization in the sense that only the points of partonic 2-surface X^2 whose $\delta M^4_\pm$ projections commute in hyper-octonionic sense and thus belong to the intersections of the projection $P_{M^4}(X^2)$ with radial light-like geodesics $M_\pm$ representing intersections of $M^2 \subset M^4 \subset M^8$ with $\delta M^4_\pm \times CP_2$ contribute to the configuration space Hamiltonians and super Hamiltonians and therefore to the configuration space metric.

Clearly, finite measurement resolution seems to be an unavoidable aspect of the geometrization of the configuration space as one can expect on basis of the fact that configuration space Clifford algebra provides representation for hyper-finite factors of type II_1 whose inclusions provide a representation for the finite measurement resolution. This means that the infinite-dimensional configuration space can be represented as a finite-dimensional space in arbitrary precise approximation so that also also configuration Clifford algebra and configuration space spinor fields becomes finite-dimensional.

The modification of anti-commutation relations to this case is

$$\{\overline{\Psi}(x_m)\gamma^0, \Psi(x_n)\} = (1+K)J\delta_{x_m,x_n} . \tag{7.12}$$

Note that the constancy of γ^0 implies a complete symmetry between the two points. The number of points must be the maximal one consistent with the Kronecker delta type anti-commutation relations so that information is not lost.

The question arises about the choice of the points x_m. This choice should general coordinate invariant. The number theoretic vision leads to the notion of number theoretic braid defined as the set of points common to real and p-adic variant of X^2. The points of the number theoretic braid are excellent candidates for points x_n. The p-adic variant exists only if X^2 is defined by rational functions with coefficients which are possibly algebraic and thus make sense both in real and p-adic sense. These points belong to the algebraic extension of rational numbers appearing in the representation of X^2 as an algebraic surface but one can consider quite generally the possibility that the points of the number theoretic braid are rational or in a finite algebraic extension of rationals. What is important that if one restricts the consideration to rational points this criterion makes sense even if X^2 is not algebraic. In the generic case one can expect that the number of these points is finite.

7.4 Configuration space geometry and hierarchy of inclusions of hyper-finite factors of II_1

The configuration space metric defined as anti-commutators of the configuration space gamma matrices is extremely degenerate since it effectively corresponds to a quadratic form in N-dimensional space, where N_m is the total number of the eigenmodes of D_K. Since two Hamiltonians whose values and corresponding Killing vector fields co-incide at the points of B are equivalent for given ray $M_\pm$, it is natural to pose a cutoff in the number of Hamiltonians used for the representation of reduced configuration space in given region inside which induced Kähler form is non-vanishing. The natural manner to pose this cutoff is by ordering the representations with respect to dimension and eigenvalue of Casimir operator for the irreducible representations of $SO(3)\times SO(4)$ in case of M^8 and for the representations of $SO(3)\times SU(3)$ in case of H.

This boils down to a hierarchy of approximate representations of the configuration space as Kähler manifold with spinor structure with a truncation of the Clifford algebra to a finite dimensional Clifford algebra. This is in spirit with the proposed interpretation of the inclusion sequence of hyper-finite factors of type II_1 and with the very notion of hyper-finiteness. A surprisingly concrete connection of the configuration space geometry with generalized eigenvalue spectrum of $D_K(X^3)$ and basic quantum physics results. For instance, from the general expression of Kähler metric in terms of Kähler function

$$G_{k\bar{l}} = \partial_k\partial_{\bar{l}}K = \frac{\partial_k\partial_{\bar{l}}exp(K)}{exp(K)} - \frac{\partial_k exp(K)}{exp(K)}\frac{\partial_{\bar{l}}exp(K)}{exp(K)} , \tag{7.13}$$

and from the expression of $exp(K) = \prod_i \lambda_i$ as the product of of finite number of eigenvalues of $D_K(X^3)$, the expression

$$G_{k\bar{l}} = \sum_i \frac{\partial_k\partial_{\bar{l}}\lambda_i}{\lambda_i} - \frac{\partial_k\lambda_i}{\lambda_i}\frac{\partial_{\bar{l}}\lambda_i}{\lambda_i} \tag{7.14}$$

for the configuration space metric follows. Here complex coordinates refer to the complex coordinates of configuration space.

A good candidate for these complex coordinates are the complex coordinates of $S^2\times S$, $S = CP_2$ or E^4, for the points of B so that a close connection with the geometry of imbedding space is obtained. Once these coordinates have been specified G can be contracted with the Killing vector fields of configuration space isometries defining the coordinates for the truncated configuration space. By studying the behavior of eigenvalue spectrum under small deformations of X_l^3 by symplectic transformations of $\delta CD \times S$ the components of G can be estimated.

8 Super-conformal symmetries at space-time and configuration space level

The physical interpretation and detailed mathematical understanding of super-conformal symmetries has developed rather slowly and has involved several side tracks. In the following I try to summarize the basic picture with minimal amount of formulas with the understanding that the statement "Noether charge associated with geometrically realized Kac-Moody symmetry" is enough for the reader to write down the needed formula explicitly.

8.1 Configuration space as a union of symmetric spaces

In finite-dimensional context globally symmetric spaces are of form G/H and connection and curvature are independent of the metric, provided it is left invariant under G. The hope is that same holds true in infinite-dimensional context. The most one can hope of obtaining is the decomposition $C(H) = \cup_i G/H_i$ over orbits of G. One could allow also symmetry breaking in the sense that G and H depend on the orbit: $C(H) = \cup_i G_i/H_i$ but it seems that G can be chosen to be same for all orbits. What is essential is that these groups are infinite-dimensional. The basic properties of the coset space decomposition give very strong constraints on the group H, which certainly contains the subgroup of G, whose action reduces to diffeomorphisms of X^3.

8.1.1 Consequences of the decomposition

If the decomposition to a union of coset spaces indeed occurs, the consequences for the calculability of the theory are enormous since it suffices to find metric and curvature tensor for single representative 3-surface on a given orbit (contravariant form of metric gives propagator in perturbative calculation of matrix elements as functional integrals over the configuration space). The representative surface can be chosen to correspond to the maximum of Kähler function on a given orbit and one obtains perturbation theory around this maximum (Kähler function is not isometry invariant).

The task is to identify the infinite-dimensional groups G and H and to understand the zero mode structure of the configuration space. Almost twenty (seven according to long held belief!) years after the discovery of the candidate for the Kähler function defining the metric, it became finally clear that these identifications follow quite nicely from $Diff^4$ invariance and $Diff^4$ degeneracy as well as special properties of the Kähler action.

The guess (not the first one!) would be following. G corresponds to the symplectic transformations of $\delta M^4_\pm \times CP_2$ leaving the induced Kähler form invariant. If G acts as isometries the values of Kähler form at partonic 2-surfaces (remember effective 2-dimensionality) are zero modes and configuration space allows slicing to symplectic orbits of the partonic 2-surface with fixed induced Kähler form. Quantum fluctuating degrees of freedom would correspond to symplectic group and to the fluctuations of the induced metric. The group H dividing G would in turn correspond to the Kac-Moody symmetries respecting light-likeness of X_l^3 and acting in X_l^3 but trivially at the partonic 2-surface X^2. This coset structure was originally discovered via coset construction for super Virasoro algebras of super-symplectic and super Kac-Moody algebras and realizes Equivalence Principle at quantum level.

8.1.2 Configuration space isometries as a subgroup of $Diff(\delta M^4_+ \times CP_2)$

The reduction to light cone boundary leads to the identification of the isometry group as some subgroup of for the group G for the diffeomorphisms of $\delta M^4_+ \times CP_2$. These diffeomorphisms indeed act in a natural manner in δCH, the the space of 3-surfaces in $\delta M^4_+ \times CP_2$. Configuration space is expected to decompose to a union of the coset spaces G/H_i, where H_i corresponds to some subgroup of G containing the transformations of G acting as diffeomorphisms for given X^3. Geometrically the vector fields acting as diffeomorphisms of X^3 are tangential to the 3-surface. H_i could depend on the topology of X^3 and since G does not change the topology of 3-surface each 3-topology defines separate orbit of G. Therefore, the union involves sum over all topologies of X^3 plus possibly other 'zero modes'. Different topologies are naturally glued together since singular 3-surfaces intermediate between two 3-topologies correspond to points common to the two sectors with different topologies.

8.2 Isometries of configuration space geometry as symplectic transformations of $\delta M^4_+ \times CP_2$

During last decade I have considered several candidates for the group G of isometries of the configuration space as the sub-algebra of the subalgebra of $Diff(\delta M^4_+ \times CP_2)$. To begin with let us write the general decomposition of $diff(\delta M^4_+ \times CP_2)$:

$$diff(\delta M^4_+ \times CP_2) \quad = \quad S(CP_2) \times diff(\delta M^4_+) \oplus S(\delta M^4_+) \times diff(CP_2) \ . \tag{8.1}$$

Here $S(X)$ denotes the scalar function basis of space X. This Lie-algebra is the direct sum of light cone diffeomorphisms made local with respect to CP_2 and CP_2 diffeomorphisms made local with respect to light cone boundary.

The idea that entire diffeomorphism group would act as isometries looks unrealistic since the theory should be more or less equivalent with topological field theory in this case. Consider now the various candidates for G.

1. The fact that symplectic transformations of CP_2 and M^4_+ diffeomorphisms are dynamical symmetries of the vacuum extremals suggests the possibility that the diffeomorphisms of the light cone boundary and symplectic transformations of CP_2 could leave Kähler function invariant and thus correspond to zero modes. The symplectic transformations of CP_2 localized with respect to light cone boundary acting as symplectic transformations of CP_2 have interpretation as local color transformations and are a good candidate for the isometries. The fact that local color transformations are not even approximate symmetries of Kähler action is not a problem: if they were exact symmetries, Kähler function would be invariant and zero modes would be in question.

2. CP_2 local conformal transformations of the light cone boundary act as isometries of δM^4_+. Besides this there is a huge group of the symplectic symmetries of $\delta M^4_+ \times CP_2$ if light cone boundary is provided with the symplectic structure. Both groups must be considered as candidates for groups of isometries. $\delta M^4_+ \times CP_2$ option exploits fully the special properties of $\delta M^4_+ \times CP_2$, and one can develop simple argument demonstrating that $\delta M^4_+ \times CP_2$ symplectic invariance is the correct option. Also the construction of configuration space gamma matrices as super-symplectic charges supports $\delta M^4_+ \times CP_2$ option.

This picture remained same for a long time. The discovery that Kac-Moody algebra consisting of X^2 local symmetries generated by Hamiltonians of isometry sub-algebra of symplectic algebra forced to challenge this picture and ask whether also X^2-local transformations of symplectic group could be involved.

1. The basic condition is that the X^2 local transformation acts leaves induced Kähler form invariant apart from diffeomorphism. Denote the infinitesimal generator of X^2 local symplecto morphism by $\Phi_A(x)j^{Ak}$, where A labels Hamiltonians in the sum and by j^α the generator of X^2 diffeomorphism.

2. The invariance of $J = \epsilon^{\alpha\beta}J_{\alpha\beta}\sqrt{g_2}$ modulo diffeomorphism under the infinitesimal symplectic transformation gives

$$\{H^A, \Phi_A\} \quad \equiv \quad \partial_\alpha H^A \epsilon^{\alpha\beta}\partial_\beta\Phi_A = \partial_\alpha J j^\alpha \ . \tag{8.2}$$

3. Note that here the Poisson bracket is not defined by $J^\alpha\beta$ but $\epsilon^{\alpha\beta}$ defined by the induced metric. Left hand side reflects the failure of symplectomorphism property due to the dependence of $\Phi_A(x)$ on X^2 coordinate which and comes from the gradients of $\delta M^4 \times CP_2$ coordinates in the expression of the induced Kähler form. Right hand side corresponds to the action of infinitesimal diffeomorphism.

4. Let us assume that one can restrict the consideration to single Hamiltonian so that the transformation is generated by $\Phi(x)H_A$ and that to each $\Phi(x)$ there corresponds a diffeomorphism of X^2, which is a symplectic transformation of X^2 with respect to symplectic form $\epsilon^{\alpha\beta}$ and generated by Hamiltonian $\Psi(x)$. This transforms the invariance condition to

$$\{H^A, \Phi\} \equiv \partial_\alpha H^A \epsilon^{\alpha\beta} \partial_\beta \Phi = \partial_\alpha J \epsilon^{\alpha\beta} \partial_\beta \Psi_A = \{J, \Psi_A\} \ . \tag{8.3}$$

This condition can be solved identically by assuming that Φ_A and Ψ are proportional to arbitrary smooth function of J:

$$\Phi = f(J) \ , \quad \Psi_A = -f(J)H_A \ . \tag{8.4}$$

Therefore the X^2 local symplectomorphisms of H reduce to symplectic transformations of X^2 with Hamiltonians depending on single coordinate J of X^2. The analogy with conformal invariance for which transformations depend on single coordinate z is obvious. As far as the anti-commutation relations for induced spinor fields are considered this means that $J = consant$ curves behave as points points. For extrema of J appearing as candidates for points of number theoretic braids $J = constant$ curves reduce to points.

5. From the structure of the conditions it is easy to see that the transformations generate a Lie-algebra. For the transformations $\Phi^1_A H^A$ $\Phi^2_A H^A$ the commutator is

$$\Phi_A^{[1,2]} = f_A^{\ BC} \Phi_B \Phi_C \ , \tag{8.5}$$

where $f_A^{\ BC}$ are the structure constants for the symplectic algebra of $\delta M^4_\pm \times CP_2$. From this form it is easy to check that Jacobi identifies are satisfied. The commutator has same form as the commutator of gauge algebra generators. BRST gauge symmetry is perhaps the nearest analog of this symmetry. In the case of isometries these transforms realized local color gauge symmetry in TGD sense.

6. If space-time surface allows a slicing to light-like 3-surfaces Y^3_l parallel to X^3_l, these conditions make sense also for the partonic 2-surfaces defined by the intersections of Y^3_l with $\delta M^4_\pm \times CP_2$ and "parallel" to X^2. The local symplectic transformations also generalize to their local variants in X^3_l. Light-likeness of X^3_l means effective metric 2-dimensionality so that 2-D Kähler metric and symplectic form as well as the invariant $J = \epsilon^{\alpha\beta} J_{\alpha\beta}$ exist. A straightforward calculation shows that the the notion of local symplectic transformation makes sense also now and formulas are exactly the same as above.

8.3 SUSY algebra defined by the anticommutation relations of fermionic oscillator operators and WCW local Clifford algebra elements as chiral super-fields

Whether TGD allows space-time supersymmetry has been a long-standing question. Majorana spinors appear in $N = 1$ super-symmetric QFTs- in particular minimally super-symmetric standard model (MSSM). Majorana-Weyl spinors appear in M-theory and super string models. An undesirable consequence is chiral anomaly in the case that the numbers of left and right handed spinors are not same. For $D = 11$ and $D = 10$ these anomalies cancel which led to the breakthrough of string models and later to M-theory. The probable reason for considering these dimensions is that standard model does not predict right-handed neutrino (although neutrino mass suggests that right handed neutrino exists) so that the numbers of left and right handed Weyl-spinors are not the same.

In TGD framework the situation is different. Covariantly constant right-handed neutrino spinor acts as a super-symmetry in CP_2. One might think that right-handed neutrino in a well-defined sense disappears from the spectrum as a zero mode so that the number of right and left handed chiralities in $M^4 \times CP_2$ would not be same. For light-like 3-surfaces covariantly constant right-handed neutrino does not however solve the counterpart of Dirac equation for a non-vanishing four-momentum and color quantum numbers of the physical state. Therefore it does not disappear from the spectrum anymore and one expects the same number of right and left handed chiralities.

In TGD framework the separate conservation of baryon and lepton numbers excludes Majorana spinors and also the the Minkowski signature of $M^4 \times CP_2$ makes them impossible. The conclusion that TGD does not allow super-symmetry is however wrong. For $\mathcal{N} = 2N$ Weyl spinors are indeed possible and if the number of right and left handed Weyl spinors is same super-symmetry is possible. In 8-D context right and left-handed fermions correspond to quarks and leptons and since color in TGD framework corresponds to CP_2 partial waves rather than spin like quantum number, also the numbers of quark and lepton-like spinors are same.

The physical picture suggest a new kind of approach to super-symmetry in the sense that the anticommutations of fermionic oscillator operators associated with the modes of the induced spinor fields define a structure analogous to SUSY algebra. This means that $\mathcal{N} = 2N$ SUSY with large N is in question allowing spins higher than two and also large fermion numbers. Recall that $\mathcal{N} \leq 32$ is implied by the absence of spins higher than two and the number of real spinor components is $N = 32$ also in TGD. The situation clearly differs from that encountered in super-string models and SUSYs and the large value of N allows to expect very powerful constraints on dynamics irrespective of the fact that SUSY is broken. Right handed neutrino modes define a sub-algebra for which the SUSY is only slightly broken by the absence of weak interactions and one could also consider a theory containing a large number of $\mathcal{N} = 2$ super-multiplets corresponding to the addition of right-handed neutrinos and antineutrinos at the wormhole throat.

Masslessness condition is essential for super-symmetry and at the fundamental level it could be formulated in terms of modified gamma matrices using octonionic representation and assuming that they span local quaternionic sub-algebra at each point of the space-time sheet. SUSY algebra has standard interpretation with respect to spin and isospin indices only at the partonic 2-surfaces so that the basic algebra should be formulated at these surfaces. Effective 2-dimensionality would require that partonic 2-surfaces can be taken to be ends of any light-like 3-surface Y_l^3 in the slicing of the region surrounding a given wormhole throat.

8.3.1 Super-algebra associated with the modified gamma matrices

Anti-commutation relations for fermionic oscillator operators associated with the induced spinor fields are naturally formulated in terms of the modified gamma matrices. Super-conformal symmetry suggests that the anti-commutation relations for the fermionic oscillator operators at light-like 3-surfaces or at their ends are most naturally formulated as anti-commutation relations for SUSY algebra. The resulting anti-commutation relations would fix the quantum TGD.

$$\begin{aligned} \{a^{\dagger}_{n\alpha}, a_{n\beta}\} &= D_{mn} D_{\alpha\beta} \ , \\ D &= (p^{\mu} + \sum_a Q^{\mu}_a)\hat{\sigma}^{\mu} \ . \end{aligned} \tag{8.6}$$

Here p^{μ} and Q^{μ}_a are space-time projections of momentum and color charges in Cartan algebra. Their action is purely algebraic. The anti-commutations are nothing but a generalization of the ordinary equal-time anticommutation relations for fermionic oscillator operators to a manifestly covariant form. The matrix $D_{m,n}$ is expected to reduce to a diagonal form with a proper normalization of the oscillator operators. The experience with extended SUSY algebra suggest that the anti-commutators could contain additional central term proportional to $\delta_{\alpha\beta}$.

One can consider basically two different options concerning the definition of the super-algebra.

1. If the super-algebra is defined at the 3-D ends of the intersection of X^4 with the boundaries of CD, the modified gamma matrices appearing in the operator D appearing in the anti-commutator are associated with Kähler action. If the generalized masslessness condition $D^2 = 0$ holds true -as suggested already earlier- one can hope that no explicit breaking of super-symmetry takes place and elegant description of massive states as effectively massless states making also possible generalization of twistor is possible. One must however notice that also massive representatives of SUSY exist.

2. SUSY algebra could be also defined at 2-D ends of light-like 3-surfaces.

According to considerations of [11] these options are equivalent for a large class of space-time sheets. If the effective 3-dimensionality realized in the sense that the effective metric defined by the modified gamma matrices is degenerate, propagation takes place along 3-D light-like 3-surfaces. This condition definitely fails for string like objects.

One can realize the local Clifford algebra also by introducing theta parameters in the standard manner and the expressing a collection of local Clifford algebra element with varying values of fermion numbers (function of CD and CP_2 coordinates) as a chiral super-field. The definition of a chiral super field requires the introduction of super-covariant derivatives. Standard form for the anti-commutators of super-covariant derivatives D_α make sense only if they do not affect the modified gamma matrices. This is achieved if p_k acts on the position of the tip of CD (rather than internal coordinates of the space-time sheet). Q_a in turn must act on CP_2 coordinates of the tip.

8.3.2 Super-fields associated with WCW Clifford algebra

WCW local Clifford algebra elements possess definite fermion numbers and it is not physically sensible to super-pose local Clifford algebra elements with different fermion numbers. The extremely elegant formulation of super-symmetric theories in terms of super-fields encourages to ask whether the local Clifford algebra elements could allow expansion in terms of complex theta parameters assigned to various fermionic oscillator operator in order to obtain formal superposition of elements with different fermion numbers. One can also ask whether the notion of chiral super field might make sense.

The obvious question is whether it makes sense to assign super-fields with the modified gamma matrices.

1. Modified gamma matrices are not covariantly constant but this is not a problem since the action of momentum generators and color generators is purely algebraic space-time coordinates.

2. One can define the notion of chiral super-field also at the fundamental level. Chiral super-field would be continuation of the local Clifford algebra of associated with CD to a local Clifford algebra element associated with the union of CDs. This would allow elegant description of cm degrees of freedom, which are the most interesting as far as QFT limit is considered.

3. Kähler function of WCW as a function of complex coordinates could be extended to a chiral super-field defined in quantum fluctuation degrees of freedom. It would depend on zero modes too. Does also the latter dependence allow super-space continuation? Coefficients of powers of theta would correspond to fermionic oscillator operators. Does this function define the propagators of various states associated with light-like 3-surface? Configuration space complex coordinates would correspond to the modes of induced spinor field so that super-symmetry would be realized very concretely.

8.4 Identification of Kac-Moody symmetries

The Kac-Moody algebra of symmetries acting as symmetries respecting the light-likeness of 3-surfaces plays a crucial role in the identification of quantum fluctuating configuration space degrees of freedom contributing to the metric.

8.4.1 Identification of Kac-Moody algebra

The generators of bosonic super Kac-Moody algebra leave the light-likeness condition $\sqrt{g_3} = 0$ invariant. This gives the condition

$$\delta g_{\alpha\beta} Cof(g^{\alpha\beta}) = 0 \ , \tag{8.7}$$

Here Cof refers to matrix cofactor of $g_{\alpha\beta}$ and summation over indices is understood. The conditions can be satisfied if the symmetries act as combinations of infinitesimal diffeomorphisms $x^\mu \to x^\mu + \xi^\mu$ of X^3 and of infinitesimal conformal symmetries of the induced metric

$$\delta g_{\alpha\beta} = \lambda(x) g_{\alpha\beta} + \partial_\mu g_{\alpha\beta}\xi^\mu + g_{\mu\beta}\partial_\alpha \xi^\mu + g_{\alpha\mu}\partial_\beta \xi^\mu \ . \tag{8.8}$$

8.4.2 Ansatz as an X^3-local conformal transformation of imbedding space

Write δh^k as a super-position of X^3-local infinitesimal diffeomorphisms of the imbedding space generated by vector fields $J^A = j^{A,k}\partial_k$:

$$\delta h^k = c_A(x) j^{A,k} . \tag{8.9}$$

This gives

$$\begin{aligned} c_A(x) & \left[D_k j_l^A + D_l j_k^A\right] \partial_\alpha h^k \partial_\beta h^l + 2\partial_\alpha c_A h_{kl} j^{A,k} \partial_\beta h^l \\ = & \lambda(x) g_{\alpha\beta} + \partial_\mu g_{\alpha\beta}\xi^\mu + g_{\mu\beta}\partial_\alpha \xi^\mu + g_{\alpha\mu}\partial_\beta \xi^\mu . \end{aligned} \tag{8.10}$$

If an X^3-local variant of a conformal transformation of the imbedding space is in question, the first term is proportional to the metric since one has

$$D_k j_l^A + D_l j_k^A = 2h_{kl} . \tag{8.11}$$

The transformations in question includes conformal transformations of $H_\pm$ and isometries of the imbedding space H.

The contribution of the second term must correspond to an infinitesimal diffeomorphism of X^3 reducible to infinitesimal conformal transformation ψ^μ:

$$2\partial_\alpha c_A h_{kl} j^{A,k} \partial_\beta h^l = \xi^\mu \partial_\mu g_{\alpha\beta} + g_{\mu\beta}\partial_\alpha \xi^\mu + g_{\alpha\mu}\partial_\beta \xi^\mu . \tag{8.12}$$

8.4.3 A rough analysis of the conditions

One could consider a strategy of fixing c_A and solving solving ξ^μ from the differential equations. In order to simplify the situation one could assume that $g_{ir} = g_{rr} = 0$. The possibility to cast the metric in this form is plausible since generic 3-manifold allows coordinates in which the metric is diagonal.

1. The equation for g_{rr} gives

$$\partial_r c_A h_{kl} j^{Ak} \partial_r h^k = 0 . \tag{8.13}$$

   The radial derivative of the transformation is orthogonal to X^3. No condition on ξ^α results. If c_A has common multiplicative dependence on $c_A = f(r) d_A$ by a one obtains

$$d_A h_{kl} j^{Ak} \partial_r h^k = 0 . \tag{8.14}$$

   so that J^A is orthogonal to the light-like tangent vector $\partial_r h^k$ X^3 which is the counterpart for the condition that Kac-Moody algebra acts in the transversal degrees of freedom only. The condition also states that the components g_{ri} is not changed in the infinitesimal transformation.

   It is possible to choose $f(r)$ freely so that one can perform the choice $f(r) = r^n$ and the notion of radial conformal weight makes sense. The dependence of c_A on transversal coordinates is constrained by the transversality condition only. In particular, a common scale factor having free dependence on the transversal coordinates is possible meaning that X^3- local conformal transformations of H are in question.

2. The equation for g_{ri} gives

$$\partial_r \xi^i = \partial_r c_A h_{kl} j^{Ak} h^{ij} \partial_j h^k . \tag{8.15}$$

The equation states that g_{ri} are not affected by the symmetry. The radial dependence of ξ^i is fixed by this differential equation. No condition on ξ^r results. These conditions imply that the local gauge transformations are dynamical with the light-like radial coordinate r playing the role of the time variable. One should be able to fix the transformation more or less arbitrarily at the partonic 2-surface X^2.

3. The three independent equations for g_{ij} give

$$\xi^\alpha \partial_\alpha g_{ij} + g_{kj}\partial_i \xi^k + g_{ki}\partial_j \xi^k \quad = \quad \partial_i c_A h_{kl} j^{Ak} \partial_j h^l \ . \tag{8.16}$$

These are 3 differential equations for 3 functions ξ^α on 2 independent variables x^i with r appearing as a parameter. Note however that the derivatives of ξ^r do not appear in the equation. At least formally equations are not over-determined so that solutions should exist for arbitrary choices of c_A as functions of X^3 coordinates satisfying the orthogonality conditions. If this is the case, the Kac-Moody algebra can be regarded as a local algebra in X^3 subject to the orthogonality constraint.

This algebra contains as a subalgebra the analog of Kac-Moody algebra for which all c_A except the one associated with time translation and fixed by the orthogonality condition depends on the radial coordinate r only. The larger algebra decomposes into a direct sum of representations of this algebra.

8.4.4 Commutators of infinitesimal symmetries

The commutators of infinitesimal symmetries need not be what one might expect since the vector fields ξ^μ are functionals c_A and of the induced metric and also c_A depends on induced metric via the orthogonality condition. What this means that $j^{A,k}$ in principle acts also to ϕ_B in the commutator $[c_A J^A, c_B J^B]$.

$$\left[c_A J^A, c_B J^B\right] \quad = \quad c_A c_B J^{[A,B]} + J^A \circ c_B J^B - J^B \circ c_A J^A \ , \tag{8.17}$$

where $\circ$ is a short hand notation for the change of c_B induced by the effect of the conformal transformation J^A on the induced metric.

Luckily, the conditions in the case $g_{rr} = g_{ir} = 0$ state that the components g_{rr} and g_{ir} of the induced metric are unchanged in the transformation so that the condition for c_A resulting from g_{rr} component of the metric is not affected. Also the conditions coming from $g_{ir} = 0$ remain unchanged. Therefore the commutation relations of local algebra apart from constraint from transversality result.

The commutator algebra of infinitesimal symmetries should also close in some sense. The orthogonality to the light-like tangent vector creates here a problem since the commutator does not obviously satisfy this condition automatically. The problem can be solved by following the recipes of non-covariant quantization of string model.

1. Make a choice of gauge by choosing time translation P^0 in a preferred M^4 coordinate frame to be the preferred generator $J^{A_0} \equiv P^0$, whose coefficient $\Phi_{A_0} \equiv \Psi(P^0)$ is solved from the orthogonality condition. This assumption is analogous with the assumption that time coordinate is non-dynamical in the quantization of strings. The natural basis for the algebra is obtained by allowing only a single generator J^A besides P^0 and putting $d_A = 1$.

2. This prescription must be consistent with the well-defined radial conformal weight for the $J^A \neq P^0$ in the sense that the proportionality of d_A to r^n for $J^A \neq P^0$ must be consistent with commutators. SU(3) part of the algebra is of course not a problem. From the Lorentz vector property of P^k it is clear that the commutators resulting in a repeated commutation have well-defined radial conformal weights only if one restricts $SO(3,1)$ to $SO(3)$ commuting with P^0. Also D could be allowed without losing well-defined radial conformal weights but the argument below excludes it. This picture conforms with the earlier identification of the Kac-Moody algebra.

   Conformal algebra contains besides Poincare algebra and the dilation $D = m^k\partial_{m^k}$ the mutually commuting generators $K^k = (m^r m_r \partial_{m^k} - 2m^k m^l \partial_{m^l})/2$. The commutators involving added generators are

$$\begin{array}{ll} \left[D, K^k\right] = -K^k \ , & \left[D, P^k\right] = P^k \ , \\ \left[K^k, K^l\right] = 0 \ , & \left[K^k, P^l\right] = m^{kl}D - M^{kl} \ . \end{array} \tag{8.18}$$

From the last commutation relation it is clear that the inclusion of K^k would mean loss of well-defined radial conformal weights.

3. The coefficient dm^0/dr of $\Psi(P^0)$ in the equation

$$\Psi(P^0)\frac{dm^0}{dr} = -J^{Ak}h_{kl}\partial_r h^l$$

is always non-vanishing due to the light-likeness of r. Since P^0 commutes with generators of $SO(3)$ (but not with D so that it is excluded!), one can *define* the commutator of two generators as a commutator of the remaining part and identify $\Psi(P^0)$ from the condition above.

4. Of course, also the more general transformations act as Kac-Moody type symmetries but the interpretation would be that the sub-algebra plays the same role as $SO(3)$ in the case of Lorentz group: that is gives rise to generalized spin degrees of freedom whereas the entire algebra divided by this sub-algebra would define the coset space playing the role of orbital degrees of freedom. In fact, also the Kac-Moody type symmetries for which c_A depends on the transversal coordinates of X^3 would correspond to orbital degrees of freedom. The presence of these orbital degrees of freedom arranging super Kac-Moody representations into infinite multiplets labeled by function basis for X^2 means that the number of degrees of freedom is much larger than in string models.

5. It is possible to replace the preferred time coordinate m^0 with a preferred light-like coordinate. There are good reasons to believe that orbifold singularity for phases of matter involving non-standard value of Planck constant corresponds to a preferred light-ray going through the tip of $\delta M^4_\pm$. Thus it would be natural to assume that the preferred M^4 coordinate varies along this light ray or its dual. The Kac-Moody group $SO(3)\times E^3$ respecting the radial conformal weights would reduce to $SO(2)\times E^2$ as in string models. E^2 would act in tangent plane of $S^2_\pm$ along this ray defining also $SO(2)$ rotation axis.

8.4.5 Hamiltonians

The action of these transformations on Kähler action is well-defined and one can deduce the conserved quantities having identification as configuration space Hamiltonians. Hamiltonians also correspond to closed 2-forms. The condition that the Hamiltonian reduces to a dual of closed 2-form is satisfied because X^2-local conformal transformations of $M^4_\pm\times CP_2$ are in question (X^2-locality does not imply any additional conditions).

8.4.6 The action of Kac-Moody algebra on spinors and fermionic representations of Kac-Moody algebra

One can imagine two interpretations for the action of generalized Kac-Moody transformations on spinors.

1. The basic goal is to deduce the fermionic Noether charge associated with the bosonic Kac-Moody symmetry and this can be done by a standard recipe. The first contribution to the charge comes from the transformation of modified gamma matrices appearing in the modified Dirac action associated with fermions. Second contribution comes from spinor rotation.

2. Both SO(3) and SU(3) rotations have a standard action as spin rotation and electro-weak rotation allowing to define the action of the Kac-Moody algebra J^A on spinors.

8.4.7 How central extension term could emerge?

The central extension term of Kac-Moody algebra could correspond to a symplectic extension which can emerge from the freedom to add a constant term to Hamiltonians as in the case of super-symplectic algebra. The expression of the Hamiltonians as closed forms could allow to understand how the central extension term emerges.

In principle one can construct a representation for the action of Kac-Moody algebra on fermions a representations as a fermionic bilinear and the central extension of Kac-Moody algebra could emerge in this construction just as it appears in Sugawara construction.

8.4.8 About the interpretation of super Kac-Moody symmetries

Also the light like 3-surfaces X_l^3 of H defining elementary particle horizons at which Minkowskian signature of the metric is changed to Euclidian and boundaries of space-time sheets can act as causal determinants, and thus contribute to the configuration space metric. In this case the symmetries correspond to the isometries of the imbedding space localized with respect to the complex coordinate of the 2-surface X^2 determining the light like 3-surface X_l^3 so that Kac-Moody type symmetry results. Also the condition $\sqrt{g_3} = 0$ for the determinant of the induced metric seems to define a conformal symmetry associated with the light like direction.

If is enough to localize only the H-isometries with respect to X_l^3, the purely bosonic part of the Kac-Moody algebra corresponds to the isometry group $M^4 \times SO(3,1) \times SU(3)$. The physical interpretation of these symmetries is not so obvious as one might think. The point is that one can generalize the formulas characterizing the action of infinitesimal isometries on spinor fields of finite-dimensional Kähler manifold to the level of the configuration space. This gives rise to bosonic generators containing also a sigma-matrix term bilinear in fermionic oscillator operators. This representation need not be equivalent with the purely fermionic representations provided by induced Dirac action. Thus one has two groups of local color charges and the challenge is to find a physical interpretation for them.

The following arguments support one possible identification.

1. The hint comes from the fact that $U(2)$ in the decomposition $CP_2 = SU(3)/U(2)$ corresponds in a well-defined sense electro-weak algebra identified as a holonomy algebra of the spinor connection. Hence one could argue that the $U(2)$ generators of either $SU(3)$ algebra might be identifiable as generators of local $U(2)_{ew}$ gauge transformations whereas non-diagonal generators would correspond to Higgs field. This interpretation would conform with the idea that Higgs field is a genuine scalar field rather than a composite of fermions.

2. Since X_l^3-local $SU(3)$ transformations represented by fermionic currents are characterized by central extension they would naturally correspond to the electro-weak gauge algebra and Higgs bosons. This is also consistent with the fact that both leptons and quarks define fermionic Kac Moody currents.

3. The fact that only quarks appear in the gamma matrices of the configuration space supports the view that action of the generators of X_l^3-local color transformations on configuration space spinor fields represents local color transformations. If the action of X_l^3-local $SU(3)$ transformations on configuration space spinor fields has trivial central extension term the identification as a representation of local color symmetries is possible.

The topological explanation of the family replication phenomenon is based on an assignment of 2-dimensional boundary to a 3-surface characterizing the elementary particle. The precise identification of this surface has remained open and one possibility is that the 2-surface X^2 defining the light light-like surface associated with an elementary particle horizon is in question. This assumption would conform with the notion of elementary particle vacuum functionals defined in the zero modes characterizing different conformal equivalences classes for X^2.

8.4.9 The relationship of the Super-Kac Moody symmetry to the standard super-conformal invariance

Super-Kac Moody symmetry can be regarded as $N = 4$ complex super-symmetry with complex H-spinor modes of H representing the 4 physical helicities of 8-component leptonic and quark like spinors acting as generators of complex dynamical super-symmetries. The super-symmetries generated by the covariantly constant right handed neutrino appear with *both* M^4 helicities: it however seems that covariantly constant neutrino does not generate any global super-symmetry in the sense of particle-sparticle mass degeneracy. Only righthanded neutrino spinor modes (apart from covariantly constant mode) appear in the expressions of configuration space gamma matrices forming a subalgebra of the full super-algebra.

$N = 2$ real super-conformal algebra is generated by the energy momentum tensor $T(z)$, $U(1)$ current $J(z)$, and super generators $G^{\pm}(z)$ carrying $U(1)$ charge. Now $U(1)$ current would correspond to right-handed neutrino number and super generators would involve contraction of covariantly constant neutrino spinor with second quantized induced spinor field. The further facts that $N = 2$ algebra is associated naturally with Kähler geometry, that the partition functions associated with $N = 2$ super-conformal representations are modular invariant, and that $N = 2$ algebra defines so called chiral ring defining a topological quantum field theory [10], lend a further support for the belief that $N = 2$ super-conformal algebra acts in super-symplectic degrees of freedom.

The values of c and conformal weights for $N = 2$ super-conformal field theories are given by

$$\begin{aligned} c &= \frac{3k}{k+2} \ , \\ \Delta_{l,m}(NS) &= \frac{l(l+2)-m^2}{4(k+2)} \ , \quad l = 0, 1, ..., k \ , \\ q_m &= \frac{m}{k+2} \ , \quad m = -l, -l+2, ..., l-2, l \ . \end{aligned} \tag{8.19}$$

q_m is the fractional value of the $U(1)$ charge, which would now correspond to a fractional fermion number. For $k = 1$ one would have $q = 0, 1/3, -1/3$, which brings in mind anyons. $\Delta_{l=0,m=0} = 0$ state would correspond to a massless state with a vanishing fermion number. Note that $SU(2)_k$ Wess-Zumino model has the same value of c but different conformal weights. More information about conformal algebras can be found from the appendix of [10].

For Ramond representation $L_0 - c/24$ or equivalently G_0 must annihilate the massless states. This occurs for $\Delta = c/24$ giving the condition $k = 2\left[l(l+2) - m^2\right]$ (note that k must be even and that $(k, l, m) = (4, 1, 1)$ is the simplest non-trivial solution to the condition). Note the appearance of a fractional vacuum fermion number $q_{vac} = \pm c/12 = \pm k/4(k+2)$. I have proposed that NS and Ramond algebras could combine to a larger algebra containing also lepto-quark type generators but this not necessary.

The conformal algebra defined as a direct sum of Ramond and NS $N = 4$ complex sub-algebras associated with quarks and leptons might further extend to a larger algebra if lepto-quark generators acting effectively as half odd-integer Virasoro generators can be allowed. The algebra would contain spin and electro-weak spin as fermionic indices. Poincare and color Kac-Moody generators would act as symplectically extended isometry generators on configuration space Hamiltonians expressible in terms of Hamiltonians of $X_l^3 \times CP_2$. Electro-weak and color Kac-Moody currents have conformal weight $h = 1$ whereas T and G have conformal weights $h = 2$ and $h = 3/2$.

The experience with $N = 4$ complex super-conformal invariance suggests that the extended algebra requires the inclusion of also second quantized induced spinor fields with $h = 1/2$ and their super-partners with $h = 0$ and realized as fermion-antifermion bilinears. Since G and Ψ are labeled by 2×4 spinor indices, super-partners would correspond to $2 \times (3 + 1) = 8$ massless electro-weak gauge boson states with polarization included. Their inclusion would make the theory highly predictive since induced spinor and electro-weak fields are the fundamental fields in TGD.

8.5 Coset space structure for configuration space as a symmetric space

The key ingredient in the theory of symmetric spaces is that the Lie-algebra of G has the following decomposition

$$\begin{aligned} & g = h + t \ , \\ & [h, h] \subset h \ , \quad [h, t] \subset t \ , \quad [t, t] \subset h \ . \end{aligned}$$

In present case this has highly nontrivial consequences. The commutator of *any* two infinitesimal generators generating nontrivial deformation of 3-surface belongs to h and thus vanishing norm in the configuration space metric at the point which is left invariant by H. In fact, this same condition follows from Ricci flatness requirement and guarantees also that G acts as isometries of the configuration space. This generalization is supported by the properties of the unitary representations of Lorentz group at the light cone boundary and by number theoretical considerations.

The algebras suggesting themselves as candidates are symplectic algebra of $\delta M^{\pm} \times CP_2$ and Kac-Moody algebra mapping light-like 3-surfaces to light-like 3-surfaces to be discussed in the next section.

The identification of the precise form of the coset space structure is however somewhat delicate.

1. The essential point is that both symplectic and Kac-Moody algebras allow representation in terms of X_l^3-local Hamiltonians. The general expression for the Hamilton of Kac-Moody algebra is

$$H = \sum \Phi_A(x) H^A \ . \tag{8.20}$$

   Here H^A are Hamiltonians of $SO(3) \times SU(3)$ acting in $\delta X_l^3 \times CP_2$. For symplectic algebra any Hamiltonian is allowed. If x corresponds to any point of X_l^3, one must assume a slicing of the causal diamond CD by translates of $\delta M_{\pm}^4$.

2. For symplectic generators the dependence of form on r^{Δ} on light-like coordinate of $\delta X_l^3 \times CP_2$ is allowed. Δ is complex parameter whose modulus squared is interpreted as conformal weight. Δ is identified as analogous quantum number labeling the modes of induced spinor field.

3. One can wonder whether the choices of the $r_M = constant$ sphere S^2 is the only choice. The Hamiltonin-Jacobi coordinate for $X^4_{X_l^3}$ suggest an alternative choice as E^2 in the decomposition of $M^4 = M^2(x) \times E^2(x)$ required by number theoretical compactification and present for known extremals of Kähler action with Minkowskian signature of induced metric. In this case $SO(3)$ would be replaced with $SO(2)$. It however seems that the radial light-like coordinate u of $X^4(X_l^3)$ would remain the same since any other curve along light-like boundary would be space-like.

4. The vector fields for representing Kac-Moody algebra must vanish at the partonic 2-surface $X^2 \subset \delta M_{\pm}^4 \times CP_2$. The corresponding vector field must vanish at each point of X^2:

$$j^k = \sum \Phi_A(x) J^{kl} H_l^A = 0 \ . \tag{8.21}$$

   This means that the vector field corresponds to $SO(2) \times U(2)$ defining the isotropy group of the point of $S^2 \times CP_2$.

   This expression could be deduced from the idea that the surfaces X^2 are analogous to origin of CP_2 at which $U(2)$ vector fields vanish. Configuration space at X^2 could be also regarded as the analog of the origin of local $S^2 \times CP_2$. This interpretation is in accordance with the original idea which however was given up in the lack of proper realization. The same picture can be deduced from braiding in which case the Kac-Moody algebra corresponds to local $SO(2) \times U(2)$ for each point of the braid at X^2. The condition that Kac-Moody generators with positive conformal weight annihilate physical states could be interpreted by stating effective 2-dimensionality in the sense that the deformations of X_l^3 preserving its light-likeness do not affect the physics. Note however that Kac-Moody type Virasoro generators do not annihilate physical states.

5. Kac-Moody algebra generator must leave induced Kähler form invariant at X^2. This is of course trivial since the action leaves each point invariant. The conditions of Cartan decomposition are satisfied. The commutators of the Kac-Moody vector fields with symplectic generators are non-vanishing since the action of symplectic generator on Kac-Moody generator restricted to X^2 gives a non-vanishing result belonging to the symplectic algebra. Also the commutators of Kac-Moody generators are Kac-Moody generators.

8.6 The relationship between super-symplectic and Super Kac-Moody algebras, Equivalence Principle, and justification of p-adic thermodynamics

The relationship between super-symplectic algebra (SS) acting at light-cone boundary and Super Kac-Moody algebra (SKM) acting on light-like 3-surfaces has remained somewhat enigmatic due to the lack of physical insights. This is not the only problem. The question to precisely what extent Equivalence Principle (EP) remains true in TGD framework and what might be the precise mathematical realization of EP is waiting for an answer. Also the justification of p-adic thermodynamics for the scaling generator L_0 of Virasoro algebra -in obvious conflict with the basic wisdom that this generator should annihilate physical states- is lacking. It seems that these three problems could have a common solution.

8.6.1 New vision about the relationship between SSV and $SKMV$

Consider now the new vision about the relationship between SSV and $SKMV$.

1. The isometries of H assignable with SKM are also symplectic transformations [5] (note that I have used the attribute "canonical" instead of "symplectic" previously). Hence might consider the possibility that SKM could be identified as a subalgebra of SS. If this makes sense, a generalization of the coset construction obtained by replacing finite-dimensional Lie group with infinite-dimensional symplectic group suggests itself. The differences of SSV and $SKMV$ elements would annihilate physical states and commute/anticommute with $SKMV$. Also the generators O_n, $n > 0$, for both algebras would annihilate the physical states so that the differences of the elements would annihilate automatically physical states for $n > 0$.

2. The super-generator G_0 contains the Dirac operator D of H. If the action of SSV and $SKMV$ Dirac operators on physical states are identical then cm of degrees of freedom disappear from the differences $G_0(SCV) - G_0(SKMV)$ and $L_0(SCV) - L_0(SKMV)$. One could interpret the identical action of the Dirac operators as the long sought-for precise realization of Equivalence Principle (EP) in TGD framework. EP would state that the total inertial four-momentum and color quantum numbers assignable to SS (imbedding space level) are equal to the gravitational four-momentum and color quantum numbers assignable to SKM (space-time level). Note that since super-symplectic transformations correspond to the isometries of the "world of classical worlds" the assignment of the attribute "inertial" to them is natural.

8.6.2 Consistency with p-adic thermodynamics

The consistency with p-adic thermodynamics provides a strong reality test and has been already used as a constraint in attempts to understand the super-conformal symmetries in partonic level.

1. In physical states the p-adic thermal expectation value of the SKM and SS conformal weights would be non-vanishing and identical and mass squared could be identified equivalently either as the expectation value of SKM or SS scaling generator L_0. There would be no need to give up Super Virasoro conditions for $SCV - SKMV$.

2. There is consistency with p-adic mass calculations for hadrons [20] since the non-perturbative SS contributions and perturbative SKM contributions to the mass correspond to space-time sheets labeled by different p-adic primes. The earlier statement that SS is responsible for the dominating non-perturbative contributions to the hadron mass transforms to a statement reflecting $SS - SKM$ duality. The perturbative quark contributions to hadron masses can be calculated most conveniently by using p-adic thermodynamics for SKM whereas non-perturbative contributions to hadron masses can be calculated most conveniently by using p-adic thermodynamics for SS. Also the proposal that the exotic analogs of baryons resulting when baryon looses its valence quarks [17] remains intact in this framework.

3. The results of p-adic mass calculations depend crucially on the number N of tensor factors contributing to the Super-Virasoro algebra. The required number is $N = 5$ and during years I have proposed several explanations for this number. It seems that holonomic contributions

that is electro-weak and spin contributions must be regarded as contributions separate from those coming from isometries. SKM algebras in electro-weak degrees and spin degrees of of freedom, would give 2+1=3 tensor factors corresponding to $U(2)_{ew} \times SU(2)$. $SU(3)$ and $SO(3)$ (or $SO(2) \subset SO(3)$ leaving the intersection of light-like ray with S^2 invariant) would give 2 additional tensor factors. Altogether one would indeed have 5 tensor factors.

There are some further questions which pop up in mind immediately.

1. Why mass squared corresponds to the thermal expectation value of the net conformal weight? This option is forced among other things by Lorentz invariance but it is not possible to provide a really satisfactory answer to this question yet. In the coset construction there is no reason to require that the mass squared equals to the integer value conformal weight for SKM algebra. This allows the possibility that mass squared has same value for states with different values of SKM conformal weights appearing in the thermal state and equals to the average of the conformal weight.

2. The coefficient of proportionality can be however deduced from the observation that the mass squared values for CP_2 Dirac operator correspond to definite values of conformal weight in p-adic mass calculations. It is indeed possible to assign to partonic 2-surface X^2 CP_2 partial waves correlating strongly with the net electro-weak quantum numbers of the parton so that the assignment of ground state conformal weight to CP_2 partial waves makes sense.

3. In the case of M^4 degrees of freedom it is strictly speaking not possible to talk about momentum eigen states since translations take parton out of δH_+. This would suggests that 4-momentum must be assigned with the tip of the light-cone containing the particle but this is not consistent with zero energy ontology. Hence it seems that one must restrict the translations of X_l^3 to time like translations in the direction of geometric future at $\delta M_+^4 \times CP_2$. The decomposition of the partonic 3-surface X_l^3 to regions $X_{l,i}^3$ carrying non-vanishing induced Kähler form and the possibility to assign $M^2(x) \subset M^4$ to the tangent space of $X^4(X_l^3)$ at points of X_l^3 suggests that the points of number theoretic braid to which oscillator operators can be assigned can carry four-momentum in the plane defined by $M^2(x)$. One could assume that the four-momenta assigned with points in given region X_i^3 are collinear but even this restriction is not necessary.

4. The additivity of conformal weight means additivity of mass squared at parton level and this has been indeed used in p-adic mass calculations. This implies the conditions

$$(\sum_i p_i)^2 = \sum_i m_i^2 \tag{8.22}$$

The assumption $p_i^2 = m_i^2$ makes sense only for massless partons moving collinearly. In the QCD based model of hadrons only longitudinal momenta and transverse momentum squared are used as labels of parton states, which together with the presence of preferred plane M^2 would suggest that one has

$$\begin{aligned} p_{i,||}^2 &= m_i^2 \ , \\ -\sum_i p_{i,\perp}^2 + 2\sum_{i,j} p_i \cdot p_j &= 0 \ . \end{aligned} \tag{8.23}$$

The masses would be reduced in bound states: $m_i^2 \to m_i^2 - (p_T^2)_i$. This could explain why massive quarks can behave as nearly massless quarks inside hadrons.

8.6.3 How it is possible to have negative conformal weights for ground states?

p-Adic mass calculations require negative conformal weights for ground states [15] . The only elegant solution of the problems caused by this requirement seems to be p-adic: the conformal weights are positive in the real sense but as p-adic numbers their dominating part is negative integer (in the real sense), which can be compensated by the conformal weights of Super Virasoro generators.

1. If $\pm\lambda_i^2$ as such corresponds to a ground state conformal weight and if λ_i is real the ground state conformal weight positive in the real sense. In complex case (instanton term) the most natural formula is $h = \pm|\lambda|^2$.

2. The first option is based on the understanding of conformal excitations in terms of CP breaking instanton term added to the modified Dirac operator. In this case the conformal weights are identified as $h = n - |\lambda_k|^2$ and the minus sign comes from the Euclidian signature of the effective metric for the modified Dirac operator. Ground state conformal weight would be non-vanishing for non-zero modes of $D(X_l^3)$. Massless bosons produce difficulties unless one has $h = |\lambda_i(1) - \lambda_i(2)|^2$, where $i = 1, 2$ refers to the two wormhole throats. In this case the difference can vanish and its non-vanishing would be due to the symmetric breaking. This scenario is assumed in p-adic mass calculations. Fermions are predicted to be always massive since zero modes of $D(X^2)$ represent super gauge degrees of freedom.

3. In the context of p-adic thermodynamics a loop hole opens allowing λ_i to be real. In spirit of rational physics suppose that one has in natural units $h = \lambda_i^2 = xp^2 - n$, where x is integer. This number is positive and large in the real sense. In p-adic sense the dominating part of this number is $-n$ and can be compensated by the net conformal weight n of Super Virasoro generators acting on the ground state. xp^2 represents the small Higgs contribution to the mass squared proportional to $(xp^2)_R \simeq x/p^2$ ($_R$ refers to canonical identification). By the basic features of the canonical identification $p > x \simeq p$ should hold true for gauge bosons for which Higgs contribution dominates. For fermions x should be small since p-adic mass calculations are consistent with the vanishing of Higgs contribution to the fermion mass. This would lead to the earlier conclusion that xp^2 and hence B_K is large for bosons and small for fermions and that the size of fermionic (bosonic) wormhole throat is large (small). This kind of picture is consistent with the p-adic modular arithmetics and suggests by the cutoff for conformal weights implied by the fact that both the number of fermionic oscillator operators and the number of points of number theoretic braid are finite. This solution is however tricky and does not conform with number theoretical universality.

8.7 Comparison of TGD and stringy views about super-conformal symmetries

The best manner to represent TGD based view about conformal symmetries is by comparison with the conformal symmetries of super string models.

8.7.1 Basic differences between the realization of super conformal symmetries in TGD and in super-string models

The realization super-symmetries in TGD framework differs from that in string models in several fundamental aspects.

1. In TGD framework super-symmetry generators acting as configuration space gamma matrices carry either lepton or quark number. Majorana condition required by the hermiticity of super generators which is crucial for super string models would be in conflict with the conservation of baryon and lepton numbers and is avoided. This is made possible by the realization of bosonic generators represented as Hamiltonians of symplectic transformations rather than vector fields generating them. This kind of representation applies also in Kac-Moody sector since the local transversal isometries localized in X_l^3 and respecting light-likeness condition can be regarded as X^2 local symplectic transformations, whose Hamiltonians generate also isometries. The fermionic representations of super-symplectic and super Kac-Moody generators can be identified as Noether charges in standard manner.

2. Super-symmetry generators can be identified as configuration space gamma matrices carrying quark and lepton numbers and the notion of super-space is not needed at all. Therefore no super-variant of geometry is needed. The distinction between Ramond and N-S representations important for $N = 1$ super-conformal symmetry and allowing only ground state weight 0 an $1/2$ disappears. Indeed, for $N = 2$ super-conformal symmetry it is already possible to generate

spectral flow transforming these Ramond and N-S representations to each other (G_n is not Hermitian anymore). This means that the interpretation of λ_i^2 (λ_i is generalized eigenvalue of $D_K(X^2)$) as ground state conformal weight does not lead to difficulties.

3. Kac-Moody and symplectic algebras generate larger algebra obtained by making symplectic algebra X^2 local. This realization of super symmetries is what distinguishes between TGD and super string models and leads to a totally different physical interpretation of super-conformal symmetries. What makes spinor field mode a generator of gauge super-symmetry is that is c-number and not an eigenmode of $D_K(X^2)$ and thus represents non-dynamical degrees of freedom. If the number of eigen modes of $D_K(X^2)$ is indeed finite means that most of spinor field modes represent super gauge degrees of freedom. One must be here somewhat cautious since bound state in the Coulomb potential associated with electric part of induced electro-weak gauge field might give rise to an infinite number of bound states which eigenvalues converging to a fixed eigenvalue (as in the case of hydrogen atom).

4. The finite number of spinor modes means that the representations of super-conformal algebras reduces to finite-dimensional ones in TGD framework and the notion of number theoretic braid indeed implies this. The physical interpretation is in terms of finite measurement resolution.

8.7.2 Basic super-conformal symmetries

The identification of explicit representations of super conformal algebras was for a long time plagued by the lack of appropriate formalism. The modified Dirac operator D_K associated with Kähler action resolves this problem if one accepts the implications of number theoretic compactification supported by what is known about preferred extremals of Kähler action and one can identify the charges associated with symplectic and Kac-Moody algebra as Noether charges. Fermionic generators can in turn be identified from the condition that they anticommute to X^2 local Hamiltonians of corresponding bosonic transformations. In case of Super Virasoro algebra Sugaware construction allows to construct super generators G.

1. Covariantly constant right handed neutrino is the fundamental generator of dynamical super conformal symmetries and appears in both leptonic and quark-like realizations of gamma matrices. Γ matrices have also Super Kac-Moody counterparts and reduce in special case to symplectic ones. Also super currents whose anti-commutators give products of corresponding Hamiltonians can be defined so that both ordinary product and Poisson bracket give rise to quark and lepton like realizations of super-symmetries. Besides this there are also electric and magnetic representations of the gamma matrices.

2. The zero modes of $D_K(X^2)$ which do not depend on the light-like radial coordinate of X_l^3 define super conformal symmetries for which any c-number spinor field generates super conformal symmetry. These symmetries are pure gauge symmetries but also them can be parameterized by Hamiltonians and by functions depending only on the coordinates of the transverse section X^2 so that one obtains also now both function algebra and symplectic algebra localized with respect to X^2. Similar picture applies in both super-symplectic and super Kac-Moody sector. In particular, one can deduce canonical expressions for the super currents associated with these super symmetries. Since all charge states are possible for the generators of these super symmetries, these super symmetries naturally correspond to those assignable to electro-weak degrees of freedom.

3. The notion of X^2 local super-symmetry makes sense if the choice of coordinates x for X^2 is specified by the inherent properties of X^2 so that same coordinates x apply for all surfaces obtained as deformations of X^2. The regions, where induced Kähler form is non-vanishing define good candidates for coordinate patches. The Hamilton-Jacobi coordinates associated with the decomposition of M^4 are a natural choice. Also geodesic coordinates can be considered. The redundancy related to rotations of coordinate axis around origin can be reduced by choosing second axis so that it connects the origin to nearest point of the number theoretic braid.

4. The diffeomorphisms of light-like coordinate of $\delta M^4_\pm$ and X_l^3 playing the role of conformal transformations. One can construct fermionic representations of as Noether charges associated

with modified Dirac action. The problem is however that that super-generators cannot be derived in this manner so that these transformations cannot be regarded as symplectic transformations. The manner to circumvent the difficulty is to construct fermionic super charges Γ_A as gamma matrices for both super symplectic and super Kac-Moody algebras in terms of generators $j^{Ak}\Gamma_k$ and corresponding Kac-Moody algebra elements T^A as fermionic super charges. From these operators super generators G can be constructed by the standard Sugawara construction allowing to interpret operators $G = T^A\Gamma_A$ as Dirac operators at the level of configuration space. By coset construction the actions of super-symplectic and super Kac-Moody Dirac operators are identical. Internal consistency requires that the Virasoro generators obtained as anticommutator $L = \{G, G^\dagger\}$ are equal to the Virasoro generators derived as fermionic Noether charges.

8.7.3 Finite measurement resolution and cutoff in the spectrum of conformal weights

The basic properties of Kähler action imply that the number generalized eigenvalues λ_i of $D_K(X^2)$ is finite. The interpretation is that the notion of finite measurement resolution is coded by Kähler action to space-time dynamics. This has also implications for the representations of super-conformal algebras.

1. The fermionic representations of various super-algebras involve only finite number of oscillator operators. Hence some kind of cutoff in the number of states reflecting the finiteness of the measurement resolution is unavoidable. A cutoff reduce integers as labels of the generators of super-conformal algebras to a finite number of integers. Finite field $G(p, 1)$ for some prime p would be a natural candidate. Since p-adic integers modulo p are in question the cutoff could relate closely to effective p-adicity and p-adic length scale-hypothesis.

2. The interpretation of the eigenvalues of the modified Dirac operator as ground state conformal weights raises the question how to represent states with conformal weights $n + \lambda_i^2$, $n > 0$. The notion of number theoretic braid allows to circumvent the difficulty. Since canonical anti-commutation relations fail, one must replace the integral representations of super-conformal generators with discrete sums over the points of number theoretic braid, the resulting representations of super-conformal algebras must reduce to representation of finite-dimensional algebras. The cutoff on conformal weight must result from the fact that the higher Virasoro generators are expressible in terms of lower ones. The cutoff is not a problem since $n < 3$ cutoff for conformal weights gives an excellent accuracy in p-adic mass calculations. A not-very-educated guess but the only one that one can imagine is that for $p \simeq 2^k$, $n_{max} = k$ defines the cutoff on allowed conformal weights.

8.7.4 What are the counter parts of stringy conformal fields in TGD framework?

The experience with string models would suggest the conformal symmetries associated with the complex coordinates of X^2 as a candidate for conformal super-symmetries. One can imagine two counterparts of the stringy coordinate z in TGD framework.

1. Super-symplectic and super Kac-Moody symmetries are local with respect to X^2 in the sense that the coefficients of generators depend on the invariant $J = \epsilon^{\alpha\beta} J_{\alpha\beta}\sqrt{g_2}$ rather than being completely free [5] . Thus the real variable J replaces complex coordinate and effective 1-dimensionality holds true also now but in different sense than for conformal field theories.

2. The slicing of X^2 by string world sheets Y^2 and partonic 2-surfaces X^2 implied by number theoretical compactification implies string-parton duality and involves the super conformal fermionic gauge symmetries associated with the coordinates u and w in the dual dimensional reductions to stringy and partonic dynamics. These coordinates define the natural analogs of stringy coordinate.

3. An further identification for TGD parts of conformal fields is inspired by $M^8 - H$ duality. Conformal fields would be fields in configuration space. The counterpart of z coordinate could be the hyper-octonionic M^8 coordinate m appearing as argument in the Laurent series of configuration space Clifford algebra elements. m would characterize the position of the tip of CD and the fractal hierarchy of CDs within CDs would give a hierarchy of Clifford algebras and

thus inclusions of hyper-finite factors of type II_1. Reduction to hyper-quaternionic field -that is field in M^4 center of mass degrees of freedom- would be needed to obtained associativity. The arguments m at various level might correspond to arguments of N-point function in quantum field theory.

8.7.5 Generalized coset representation

X^2 local super-symplectic algebra as super Kac-Moody algebra as sub-algebra. Since X^2 locality corresponds to a full 2-D gauge invariance, one can conclude that SKM is in well defined sense sub-algebra of super-symplectic algebra so that generalized coset construction makes sense and generalizes Equivalence Principle in the sense that not only four-momenta but all analogous quantum numbers associated with SKM and SS algebras are identical.

1. In this framework the ground state conformal weights associated with both super-symplectic and super Kac-Moody algebras can be identified as squares of the eigenvalues λ_i of $D_K(X^2)$. This identification together with p-adic mass thermodynamics predicts that λ_i^2 gives to mass squared a contribution analogous to the square of Higgs vacuum expectation. This identification would resolve the long-standing problem of identifying the values of these ground state conformal weights for super-conformal algebras and give a direct connection with Higgs mechanism.

2. The identification of SKM as a sub-algebra of super-symplectic algebra becomes more convincing if the light-like coordinate r allows lifting to a light-like coordinate of H. This is achieved if r is identified as coordinate associated with a light-like curve whose tangent at point $x \in X_l^3$ is light-like vector in $M^2(x) \subset T(X^4(X^3)$. With this interpretation of SKM algebra as sub-algebra of super-symplectic algebra becomes natural.

3. The existence of a lifting of SS and SKM algebras to entire H would solve the problems. The lifting problem is obviously non-trivial only in M^4 degrees of freedom. Suppose that the existence of an integrable distribution of planes $M^2(x)$ and their orthogonal complements $E^2(x)$ belonging to the tangent space of M^4 projection $P_{M^4}(X^4(X^3))$ characterizes the preferred extremals with Minkowskian signature of induced metric. In this case the lifting of the super-symplectic and super Kac-Moody algebras to entire H is possible. The local degrees of freedom contributing to the configuration space metric would belong to the integrable distribution of orthogonal complements $E^2(x)$ of $M^2(x)$ having physical interpretation as planes of physical polarizations.

Books related to TGD

[1] M. Pitkänen. Basic Properties of CP_2 and Elementary Facts about p-Adic Numbers. In *Towards M-matrix*. Onlinebook. http://tgdtheory.com/public_html/pdfpool/append.pdf, 2006.

[2] M. Pitkänen. Is it Possible to Understand Coupling Constant Evolution at Space-Time Level? In *Towards M-Matrix*. Onlinebook. http://tgdtheory.com/public_html/tgdquant/tgdquant.html#rgflow, 2006.

[3] M. Pitkänen. Basic Extremals of Kähler Action. In *Physics in Many-Sheeted Space-Time*. Onlinebook. http://tgdtheory.com/public_html/tgdclass/tgdclass.html#class, 2006.

[4] M. Pitkänen. Configuration Space Spinor Structure. In *Quantum Physics as Infinite-Dimensional Geometry*. Onlinebook. http://tgdtheory.com/public_html/tgdgeom/tgdgeom.html#cspin, 2006.

[5] M. Pitkänen. Construction of Configuration Space Kähler Geometry from Symmetry Principles. In *Quantum Physics as Infinite-Dimensional Geometry*. Onlinebook. http://tgdtheory.com/public_html/tgdgeom/tgdgeom.html#compl1, 2006.

[6] M. Pitkänen. Construction of Quantum Theory: M-matrix. In *Towards M-Matrix*. Onlinebook. http://tgdtheory.com/public_html/tgdquant/tgdquant.html#towards, 2006.

[7] M. Pitkänen. Construction of Quantum Theory: Symmetries. In *Towards M-Matrix*. Onlinebook. http://tgdtheory.com/public_html/tgdquant/tgdquant.html#quthe, 2006.

[8] M. Pitkänen. Cosmic Strings. In *Physics in Many-Sheeted Space-Time*. Onlinebook. http://tgdtheory.com/public_html/tgdclass/tgdclass.html#cstrings, 2006.

[9] M. Pitkänen. Dark Matter Hierarchy and Hierarchy of EEGs. In *TGD and EEG*. Onlinebook. http://tgdtheory.com/public_html/tgdeeg/tgdeeg.html#eegdark, 2006.

[10] M. Pitkänen. Does TGD Predict the Spectrum of Planck Constants? In *Towards M-Matrix*. Onlinebook. http://tgdtheory.com/public_html/tgdquant/tgdquant.html#Planck, 2006.

[11] M. Pitkänen. Does the Modified Dirac Equation Define the Fundamental Action Principle? In *Quantum Physics as Infinite-Dimensional Geometry*. Onlinebook. http://tgdtheory.com/public_html/tgdgeom/tgdgeom.html#Dirac, 2006.

[12] M. Pitkänen. Identification of the Configuration Space Kähler Function. In *Quantum Physics as Infinite-Dimensional Geometry*. Onlinebook. http://tgdtheory.com/public_html/tgdgeom/tgdgeom.html#kahler, 2006.

[13] M. Pitkänen. Knots and TGD. In *Quantum Physics as Infinite-Dimensional Geometry*. Onlinebook. http://tgdtheory.com/public_html/tgdgeom/tgdgeom.html#knotstgd, 2006.

[14] M. Pitkänen. Langlands Program and TGD. In *TGD as a Generalized Number Theory*. Onlinebook. http://tgdtheory.com/public_html/tgdnumber/tgdeeg/tgdnumber.html#Langlandia, 2006.

[15] M. Pitkänen. Massless states and particle massivation. In *p-Adic Length Scale Hypothesis and Dark Matter Hierarchy*. Onlinebook. http://tgdtheory.com/public_html/paddark/paddark.html#mless, 2006.

[16] M. Pitkänen. Negentropy Maximization Principle. In *TGD Inspired Theory of Consciousness*. Onlinebook. http://tgdtheory.com/public_html/tgdconsc/tgdconsc.html#nmpc, 2006.

[17] M. Pitkänen. New Particle Physics Predicted by TGD: Part I. In *p-Adic Length Scale Hypothesis and Dark Matter Hierarchy*. Onlinebook. http://tgdtheory.com/public_html/paddark/paddark.html#mass4, 2006.

[18] M. Pitkänen. Nuclear String Hypothesis. In *p-Adic Length Scale Hypothesis and Dark Matter Hierarchy*. Onlinebook. http://tgdtheory.com/public_html/paddark/paddark.html#nuclstring, 2006.

[19] M. Pitkänen. *p-Adic length Scale Hypothesis and Dark Matter Hierarchy*. Onlinebook. http://tgdtheory.com/public_html/paddark/paddark.html, 2006.

[20] M. Pitkänen. p-Adic Particle Massivation: Hadron Masses. In *p-Adic Length Scale Hypothesis and Dark Matter Hierarchy*. Onlinebook. http://tgdtheory.com/public_html/paddark/paddark.html#mass3, 2006.

[21] M. Pitkänen. Quantum Astrophysics. In *Physics in Many-Sheeted Space-Time*. Onlinebook. http://tgdtheory.com/public_html/tgdclass/tgdclass.html#qastro, 2006.

[22] M. Pitkänen. *Quantum TGD*. Onlinebook. http://tgdtheory.com/public_html/tgdquant/tgdquant.html, 2006.

[23] M. Pitkänen. TGD and Astrophysics. In *Physics in Many-Sheeted Space-Time*. Onlinebook. http://tgdtheory.com/public_html/tgdclass/tgdclass.html#astro, 2006.

[24] M. Pitkänen. TGD and Cosmology. In *Physics in Many-Sheeted Space-Time*. Onlinebook. http://tgdtheory.com/public_html/tgdclass/tgdclass.html#cosmo, 2006.

[25] M. Pitkänen. TGD as a Generalized Number Theory: Infinite Primes. In *TGD as a Generalized Number Theory*. Onlinebook. http://tgdtheory.com/public_html/tgdnumber/tgdnumber.html#visionc, 2006.

[26] M. Pitkänen. TGD as a Generalized Number Theory: p-Adicization Program. In *TGD as a Generalized Number Theory*. Onlinebook. http://tgdtheory.com/public_html/tgdnumber/tgdnumber.html#visiona, 2006.

[27] M. Pitkänen. TGD as a Generalized Number Theory: Quaternions, Octonions, and their Hyper Counterparts. In *TGD as a Generalized Number Theory*. Onlinebook. http://tgdtheory.com/public_html/tgdnumber/tgdnumber.html#visionb, 2006.

[28] M. Pitkänen. The Notion of Wave-Genome and DNA as Topological Quantum Computer. In *Genes and Memes*. Onlinebook. http://tgdtheory.com/public_html/genememe/genememe.html#gari, 2006.

[29] M. Pitkänen. Twistors, N=4 Super-Conformal Symmetry, and Quantum TGD. In *Towards M-Matrix*. Onlinebook. http://tgdtheory.com/public_html/tgdquant/tgdquant.html#twistor, 2006.

[30] M. Pitkänen. Was von Neumann Right After All. In *Towards M-Matrix*. Onlinebook. http://tgdtheory.com/public_html/tgdquant/tgdquant.html#vNeumann, 2006.

[31] M. Pitkänen. Yangian Symmetry, Twistors, and TGD. In *Towards M-Matrix*. Onlinebook. http://tgdtheory.com/public_html/tgdquant/tgdquant.html#Yangian, 2006.

[32] M. Pitkänen. Motives and Infinite Primes. In *TGD as a Generalized Number Theory*. Onlinebook. http://tgdtheory.com/public_html/tgdnumber/tgdnumber.html#infmotives, 2011.

Articles about TGD

[1] M. Pitkänen. Further Progress in Nuclear String Hypothesis. http://tgdtheory.com/public_html/articles/nuclstring.pdf, 2007.

[2] M. Pitkänen. Physics as Infinite-dimensional Geometry I: Identification of the Configuration Space Kähler Function. https://www.createspace.com/3569411, July 2010.

[3] M. Pitkänen. Physics as Infinite-dimensional Geometry II: Configuration Space Kähler Geometry from Symmetry Principles. https://www.createspace.com/3569411, July 2010.

[4] M. Pitkänen. Physics as Generalized Number Theory III: Infinite Primes. https://www.createspace.com/3569411, July 2010.

[5] M. Pitkänen. Physics as Infinite-dimensional Geometry IV: Weak Form of Electric-Magnetic Duality and Its Implications. https://www.createspace.com/3569411, July 2010.

Mathematics

[1] Analytization trick. http://en.wikipedia.org/wiki/Analytization_trick.

[2] Kac-Moody algebra. http://en.wikipedia.org/wiki/KacMoody_algebra.

[3] Malcev algebra. http://en.wikipedia.org/wiki/Malcev_algebra.

[4] Octonions. http://en.wikipedia.org/wiki/Octonions.

[5] Quaternions. http://en.wikipedia.org/wiki/Quaternion.

[6] Scale invariance vs. conformal invariance. http://en.wikipedia.org/wiki/Conformal_field_theory#Scale_invariance_vs._conformal_invariance.

[7] Seven-dimensional cross product. http://en.wikipedia.org/wiki/Seven-dimensional_cross_product.

[8] Super Virasoro algebra. http://en.wikipedia.org/wiki/Super_Virasoro_algebra.

[9] Z. I. Borevich and I. R. Shafarevich. *Number Theory.* Academic Press, 1966.

[10] G. Sierra C. Gomez, M. Ruiz-Altaba. *Quantum Groups and Two-Dimensional Physics.* Cambridge University Press, Cambridge, 1996.

[11] M. L. Ge C. N. Yang. *Braid Group, Knot Theory, and Statistical Mechanics.* World Scientific, 1989.

[12] J. Dixmier. *Von Neumann Algebras.* North-Holland, Amsterdam, 1981.

[13] F. R. Jones. *Braid groups, Hecke algebras and type II_1 factors.* 1983.

[14] C. Kassel. *Quantum Groups.* Springer Verlag, 1995.

[15] S. Sawin. Links, Quantum Groups, and TQFT's. `http://arxiv.org/abs/q-alg/9506002`, 1995.

[16] H. Sugawara. A field theory of currents. *Phys. Rev.*, 176, 1968.

[17] E. Witten. Quantum field theory and the Jones polynomial. *Comm. Math. Phys.*, 121:351–399, 1989.

Theoretical Physics

[1] Self-Organized Criticality. `http://en.wikipedia.org/wiki/Self-organized_criticality`.

[2] B. Schwartz J. H. Green, M. and E. Witten. *Superstring Theory.* Cambridge University Press, Cambridge, 1987.

[3] A. Lakthakia. *Beltrami Fields in Chiral Media*, volume 2. World Scientific, Singapore, 1994.

[4] H. Larsen M. Freedman and Z. Wang. A modular functor which is universal for quantum computation. *Comm. Math. Phys.*, 1(2):605–622, 2002.

[5] J. H. Schwartz. *Super strings. The first 15 years of Superstring Theory.* World Scientific, 1985.

Cosmology and Astro-Physics

[1] D. Da Roacha and L. Nottale. Gravitational Structure Formation in Scale Relativity. `http://arxiv.org/abs/astro-ph/0310036`, 2003.