

# The Recent View about Twistorialization in TGD Framework

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## Abstract

The recent view about the twistorialization in TGD framework is discussed.

1. A proposal made already earlier is that scattering diagrams as analogs of twistor diagrams are constructible as tree diagrams for CDs connected by free particle lines. Loop contributions are not even well-defined in zero energy ontology (ZEO) and are in conflict with number theoretic vision. The coupling constant evolution would be discrete and associated with the scale of CDs (p-adic coupling constant evolution) and with the hierarchy of extensions of rationals defining the hierarchy of adelic physics.
2. Logarithms appear in the coupling constant evolution in QFTs. The identification of their number theoretic versions as rational number valued functions required by number-theoretical universality for both the integer characterizing the size scale of CD and for the hierarchy of Galois groups leads to an answer to a long-standing question what makes small primes and primes near powers of them physically special. The primes  $p \in \{2, 3, 5\}$  indeed turn out to be special from the point of view of number theoretic logarithm.
3. The reduction of the scattering amplitudes to tree diagrams is in conflict with unitarity in 4-D situation. The imaginary part of the scattering amplitude would have discontinuity proportional to the scattering rate only for many-particle states with light-like total momenta. Scattering rates would vanish identically for the physical momenta for many-particle states.

In TGD framework the states would be however massless in 8-D sense. Massless pole corresponds now to a continuum for  $M^4$  mass squared and one would obtain the unitary cuts from a pole at  $P^2 = 0$ ! Scattering rates would be non-vanishing only for many-particle states having light-like 8-momentum, which would pose a powerful condition on the construction of many-particle states.

This idea does not make sense for incoming/outgoing particles, which light-like momenta unless they are parallel: their total momentum cannot be light-like in the general case. Rather,  $P^2 = 0$  applies to the states formed inside CDs from groups of incoming and outgoing particles. BCFW deformation  $p_i \rightarrow p_i + zr_i$  describes what happens for the single-particle momenta: they cease to be light-like but the total momenta for subgroups of particles in factorization channels are complex and light-like. This strong form of conformal symmetry has highly non-trivial implications concerning color confinement.

4. The key idea is number theoretical discretization in terms of “cognitive representations” as space-time time points with  $M^8$ -coordinates in an extension of rationals and therefore shared by both real and various p-adic sectors of the adèle. Discretization realizes measurement resolution, which becomes an inherent aspect of physics rather than something forced by observed as outsider. This fixes the space-time surface completely as a zero locus of real or imaginary part of octonionic polynomial.

This must imply the reduction of “world of classical worlds” (WCW) corresponding to a fixed number of points in the extension of rationals to a finite-dimensional discretized space with maximal symmetries and Kähler structure.

The simplest identification for the reduced WCW would be as complex Grassmannian - a more general identification would be as a flag manifold. More complex options can of course be considered. The Yangian symmetries of the twistor Grassmann approach known to act as diffeomorphisms respecting the positivity of Grassmannian and emerging also in its TGD variant would have an interpretation as general coordinate invariance

for the reduced WCW. This would give a completely unexpected connection with supersymmetric gauge theories and TGD.

5.  $M^8$  picture implies the analog of SUSY realized in terms of polynomials of super-octonions whereas  $H$  picture suggests that supersymmetry is broken in the sense that many-fermion states as analogs of components of super-field at partonic 2-surfaces are not local. This requires breaking of SUSY. At  $M^8$  level the breaking could be due to the reduction of Galois group to its subgroup  $G/H$ , where  $H$  is normal subgroup leaving the point of cognitive representation defining space-time surface invariant. As a consequence, local many-fermion composite in  $M^8$  would be mapped to a non-local one in  $H$  by  $M^8 - H$  correspondence.

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## 1 Introduction

The construction of scattering amplitudes is a dream that I have had since the birth of TGD for four decades ago. Various ideas have gradually emerged, some of them have turned out to be wrong, and some of them have survived. At this age I must admit that the dream about explicit algorithms that any graduate student could apply to construct the scattering amplitudes, would require a collective effort and probably will not be realized during my lifetime.

I have however identified a set of general powerful principles leading to a generalization of the recipes for constructing twistorial amplitudes and already now these principles suggest the possibility of rather concrete realizations. In the sequel several additional insights are developed in more detail. Some of them are discussed already earlier in the formulation of  $M^8 - H$  duality [L5] in adelic framework [L6, L7] and in the chapters developing the TGD based generalization of twistor Grassmannian approach [K11, K19, K18, K20].

1. A proposal made already earlier [K20] is that scattering diagrams as analogs of twistor diagrams are constructible as tree diagrams for CDs connected by free particle lines. Loop contributions are not even well-defined in zero energy ontology (ZEO) and are in conflict with number theoretic vision. The coupling constant evolution would be discrete and associated with the scale of CDs (p-adic coupling constant evolution) and with the hierarchy of extensions of rationals defining the hierarchy of adelic physics.
2. Logarithms appear in the coupling constant evolution in QFTs. The identification of their number theoretic versions as rational number valued functions required by number-theoretical universality for both the integer characterizing the size scale of CD and for the hierarchy of Galois groups leads to an answer to a long-standing question what makes small primes and primes near powers of them physically special. The primes  $p \in \{2, 3, 5\}$  indeed turn out to be special from the point of view of number theoretic logarithm.
3. The reduction of the scattering amplitudes to tree diagrams is in conflict with unitarity in 4-D situation. The imaginary part of the scattering amplitude would have discontinuity proportional to the scattering rate only for many-particle states with light-like total momenta. Scattering rates would vanish identically for the physical momenta for many-particle states.

In TGD framework the states would be however massless in 8-D sense. Massless pole corresponds now to a continuum for  $M^4$  mass squared and one would obtain the unitary cuts from a pole at  $P^2 = 0$ ! Scattering rates would be non-vanishing only for many-particle states having light-like 8-momentum, which would pose a powerful condition on the construction of many-particle states. Single particle momenta cannot be however light-like for this kind of states unless they are parallel. They must be also complex as they indeed are already in classical TGD.

In fact, BCFW deformation  $p_i \rightarrow p_i + z r_i$ ,  $r_i \cdot r_j = 0$  creates at  $z$ -poles of the resulting amplitude pairs of zero energy states for which complex single particle momenta are not light-like but sum up to massless momentum. One can interpret these zero energy analogs of resonances, states inside CDs formed from massless external particles as they arrive to CD. This strong form of conformal symmetry has highly non-trivial implications concerning color confinement.

4. The key idea is number theoretical discretization [L6] in terms of “cognitive representations” as space-time time points with  $M^8$ -coordinates in an extension of rationals and therefore shared by both real and various p-adic sectors of the adele. Discretization realizes measurement resolution, which becomes an inherent aspect of physics rather than something forced by observed as outsider. This fixes the space-time surface completely as a zero locus of real or imaginary part of octonionic polynomial.

This must imply the reduction of “world of classical worlds” (WCW) corresponding to a fixed number of points in the extension of rationals to a finite-dimensional discretized space with maximal symmetries and Kähler structure [K4, K1, K15].

The simplest identification for the reduced WCW would be as complex Grassmannian - a more general identification would be as a flag manifold. More complex options can of course be considered. The Yangian symmetries of the twistor Grassmann approach known to act as diffeomorphisms respecting the positivity of Grassmannian and emerging also in its TGD variant would have an interpretation as general coordinate invariance for the reduced WCW. This would give a completely unexpected connection with supersymmetric gauge theories and TGD.

5.  $M^8$  picture [L5] implies the analog of SUSY realized in terms of polynomials of super-octonions whereas  $H$  picture suggests that supersymmetry is broken in the sense that many-fermion states as analogs of components of super-field at partonic 2-surfaces are not local. This requires breaking of SUSY. At  $M^8$  level the breaking could be due to the reduction of Galois group to its subgroup  $G/H$ , where  $H$  is normal subgroup leaving the point of cognitive representation defining space-time surface invariant. As a consequence, local many-fermion composite in  $M^8$  would be mapped to a non-local one in  $H$  by  $M^8 - H$  correspondence.

## 2 General view about the construction of scattering amplitudes in TGD framework

Before twistorial considerations a general vision about the basic principles of TGD and construction of scattering amplitudes in TGD framework is in order.

### 2.1 General principles behind S-matrix

Although explicit formulas for scattering amplitudes are probably too much to hope, one can try to develop a convincing general view about principles behind the S-matrix.

#### 2.1.1 World of Classical Worlds

The first discovery was what I called the “world of classical worlds” (WCW) [K4, K1, K15] as a generalization of loop space allowing to replace path integral approach failing in TGD work. This led to a generalization of Einstein’s geometrization program to an attempt to geometrize entire quantum physics. The geometry of WCW would be essentially unique from its mere existence since the existence of Riemann connection requires already in the case of loop spaces maximal isometries. Super-symplectic and super-conformal symmetries generalizing the 2-D conformal symmetries by replacing 2-D surfaces with light-like 3-surfaces (metrically 2-D!) would define the isometries.

Physical states would be classical spinor fields in the infinite-dimensional WCW and spinors at given point of WCW would be fermionic Fock states. Gamma matrices would be linear combinations of fermionic oscillator operators associated with the analog of massless Dirac equation at space-time surface determined by the variational principle whose preferred extremals the space-time surfaces are. Strong form of holography implied by strong form of general coordinate invariance would imply that it is enough to consider the restrictions of the induced spinor fields at string world sheets and partonic 2-surfaces (actually at discrete points at them defining the ends of boundaries of string world sheets) [K13, K15].

### 2.1.2 Zero Energy Ontology and generalization of quantum measurement theory to a theory of consciousness

The attempts to understand S-matrix led to the question about what does state function reduction really mean. This eventually led to the discovery of Zero Energy Ontology (ZEO) in which time=constant snapshot as a physical state is replaced with preferred extremal satisfying infinite number of additional gauge conditions [L8]. Temporal pattern becomes the fundamental entity: this conforms nicely with the view neuroscientists and computational scientists for whom behavior and program are basic notions. One can say that non-deterministic state function reduction replaces this kind time evolution with new one. One gets rid of the basic difficulty of ordinary quantum measurement theory.

Causal diamond (CD) is the basic geometric object of ZEO. The members of the state pair defining zero energy state - the analog of physical event characterized by initial and final states - have opposite total conserved quantum numbers and reside at the opposite light-like boundaries of CD being associated with 3-surfaces connected by a space-time surface, the preferred extremal. CDs form a fractal hierarchy ordered by their discrete size scale.

One ends up to a quite radical prediction: the arrow of time changes in “big” state function reduction changing the roles of active and passive boundaries of CD. The state function reductions occurring in elementary reactions represent an example of “big” state function reduction. The sequence of “small” state function reductions - analogs of so called weak measurements - defines self as a conscious entity having CD as imbedding space correlate [L8].

In ZEO based view about WCW 3-surfaces  $X^3$  are pairs of 3-surfaces at boundaries of CD connected by preferred extremals of the action principle. WCW spinors are pairs of fermionic Fock states at these 3-surfaces and WCW spinor fields are WCW spinors depending on  $X^3$ . They satisfy the analog of massless Dirac equation which boils down to the analogs of Super Virasoro conditions including also gauge conditions for a sub-algebra of super-symplectic algebra. S-matrix describing time evolution followed by “small” state function reduction relates two WCW spinor fields of this kind.

### 2.1.3 Generalization of twistor Grassmannian approach to TGD framework

Twistorial approach generalizes from  $M^4$  to  $H = M^4 \times CP_2$ . One possible motivation could be the fact that ordinary twistor approach describes only scattering of massless particles. In the proposed generalization particles are massless in 8-D sense and in general massive in 4-D sense [K11, K19, K18, K20].

1. The existence of twistor lift of Kähler action as 6-D analog of Kähler action fixes the choice of  $H$  uniquely: only  $M^4$  and  $CP_2$  allow twistor space with Kähler structure. The 12-D product of the twistor spaces of  $M^4$  and  $CP_2$  induces twistor structure for 6-D surface  $X^6$  under additional conditions guaranteeing that the  $X^6$  is twistor space of 4-D surface  $X^4$  ( $S^2$  bundle over  $X^4$ ) - its twistor lift. The conjecture that 6-D Kähler action indeed gives rise to twistor spaces of  $X^4$  as preferred extremals.
2. This conjecture is the analog for Penrose’s original twistor representation of Maxwellian fields reducing dynamics of massless fields to homology. There is also an analogy with massless fields. Dimensional reduction of Kähler action occurs for 6-surfaces, which represent twistor spaces and the external particles entering CD would be minimal surfaces defining simultaneous preferred extremals of Kähler action satisfying infinite number of additional gauge conditions. Minimal surfaces indeed satisfy generalization of massless field equations. In the interior of CD defining interaction region there is a coupling to Kähler 4-force and one has analog of massless particle coupling to Maxwellian field.
3. 6-D Kähler action would give the preferred extremals via the analog of dimensional reduction essential for the twistor space property requiring that one has  $S^2$  bundle over space-time surface. I have considered the generalization of the standard twistorial construction of scattering amplitudes of  $\mathcal{N} = 4$  SUSY to TGD context. In particular, the crucial Yangian invariance of the amplitudes holds true also now in both  $M^4$  and  $CP_2$  sectors.

4. Skeptic could argue that TGD generalization of twistors does not tell anything about the origin of the Yangian symmetry. During writing of this contribution I however realized that the hierarchy of Grassmannians realizing the Yangian symmetries could be seen as a hierarchy of reduced WCWs associated with the hierarchy of adeles defined by the hierarchy of extensions of rationals. The isometries of Grassmannian would emerge in the reduction of the isometry group of WCW to a finite-D isometry group of Grassmannian and would be caused by finite measurement resolution described number theoretically. Of course, one can consider also more general flag manifolds with Kähler property as candidates for the analogs of Grassmannians. I will represent the argument in more detail later.

This could also relate to the postulated infinite hierarchy of hyper-finite factors of type  $II_1$  (HFFs) [K12, K3] as a correlate for the finite measurement resolution with included sub-factor inducing transformations which act trivially in the measurement resolution used.

**Remark:** There is an amusing connection with empiria. Topologist Barbara Shipman observed that honeybee dance allows a description in terms of flag manifold  $F = SU(3)/U(1) \times U(1)$ , which is the space for the choices of quantization axes of color quantum numbers and also the twistor space in  $CP_2$  degrees of freedom [A1]. This suggests that QCD type physics might make sense in macroscopic length scales. p-Adic length scale hypothesis and the predicted long range classical color gauge fields suggest a hierarchy of QCD type physics. One can indeed construct a TGD based model of honeybee dance with a concrete interpretation and representation for the points of  $F$  at space-time level [L9].

#### 2.1.4 $M^8 - H$ duality

$M^8 - H$  duality provides two equivalent manners to see the dynamics with either  $M^8$  or  $H = M^4 \times CP_2$  as imbedding space [L5]. One might speak of number theoretic compactification which is a completely non-dynamical analog for spontaneous compactification.

1. In  $M^8$  picture the space-time corresponds to a zero locus for either imaginary part  $IM(P)$  or real part  $RE(P)$  of octonionic polynomial ( $RE(o)$  and  $IM(o)$  are defined by the decomposition  $o = RE(o) + I_4 IM(o)$ , where  $I_4$  is octonion unit orthogonal to quaternionic subalgebra). The dynamics is purely algebraic and ultra-local.
2. At the level of  $H$  the dynamics is dictated by variational principle and partial differential equations. Space-time surfaces are preferred extremals of the twistor lift of Kähler action reduced to a sum of 4-D Kähler action and volume term analogous to cosmological term in GRT. The equivalence of these descriptions gives powerful constraints and should follow from the infinite number of gauge conditions at the level of  $H$  associated with a sub-algebra of supersymplectic algebra implying the required dramatic reduction of degrees of freedom [K1, K15]. One has a hierarchy of these sub-algebras, which presumably relates to the hierarchy of HFFs and hierarchy of extensions of rationals.

$H$  picture works very nicely in applications. For instance, the notions of field body and magnetic body are crucial in all applications.

The notion of quaternionicity, which is a central element of  $M^8 - H$  duality has a deep connection with causality which I have not noticed earlier. At the level of momentum space quaternionicity means that 8-momenta -, which by  $M^8 - H$ -duality correspond to 4-momenta at level of  $M^4$  and color quantum numbers at the level of  $CP_2$  - are quaternionic. Quaternionicity means that the time component of 8-momentum, which is parallel to real octonion unit, is non-vanishing. The 8-momentum itself must be time-like, in fact light-like. In this case one can always regard the momentum as momentum in some quaternionic sub-space. Causality requires a fixed sign for the time component of the momentum.

It must be however noticed that 8-momentum can be complex: also the 4-momentum can be complex at the level of  $M \times CP_2$  already classically. A possible interpretation is in terms of decay width as part of momentum as it indeed is in phenomenological description of unstable particles.

Could one require that the quaternionic momenta form a linear space with respect to octonionic sum? This is the case if the energy - that is the time-like part parallel to the real octonionic unit

- has a fixed sign. The sum of the momenta is quaternionic in this case since the sum of light-like momenta is in general time-like and in special case light-like. If momenta with opposite signs of energy are allowed, the sum can become space-like and the sum of momenta is co-quaternionic.

This result is technically completely trivial as such but has a deep physical meaning. Quaternionicity at the level of 8-momenta implies standard view about causality: only time-like or at most light-like momenta and fixed sign of time-component of momentum.

### 2.1.5 Adelic physics

The adelicization of ordinary physics fusing real number based physics and various p-adic variants of physics in order to describe cognition.

1. Adelic physics [L6, L7] gives powerful number theoretic constraints when combined with  $M^8 - H$  duality and leads to the vision about evolutionary hierarchy defined by extensions of rationals. The higher the level in the hierarchy, the higher the dimension  $n$  of the extension identified in terms of Planck constant  $h_{eff}/h = n$  labelling the levels of dark matter hierarchy.
2. Adelic hypothesis allows to sharpen the strong form of holography to a statement that discrete cognitive representations consisting of a finite number of points identified as points of space-time surface with  $M^8$  coordinates in the extension of rationals fixes the space-time surface itself. This dramatic reduction would be basically due to finite measurement resolution realized as an inherent property of dynamics. Cognitive representation in fact gives the WCW coordinates of the space-time surface in WCW! WCW reduces to a number theoretic discretization of a finite-dimensional space with Kähler structure and presumably maximal isometries.
3. In ZEO space-time surface becomes analogous to a computer program determined in terms of finite net of numbers! Of course, at the QFT limit of TGD giving standard model and GRT space-time is locally much more complex since one approximates the many-sheeted space-time with single slightly curved region of  $M^4$ . This is the price paid for getting rid (or losing) the topological richness of the many-sheeted space-time crucial for the understanding living matter and even physics in galactic scales.
4. Skeptic can argue that this discretization of WCW leads to the loss of WCW geometry based on real numbers. One can however consider also continuous values for the points of cognitive representations and assigning metric to the points of cognitive representation. Metric could be defined as kind of induced metric. One slices CD by parallel CDs by shift the CD along the axis connecting its tips. This allows to see the point of cognitive representation as point at one particular CD. One shifts slightly the point along its CD. Imbedding space metric allows to deduce the infinitesimal line element  $ds^2$  and to deduce the metric components. This allows a definition of differential geometry so that the analog of WCW metric makes sense as a hierarchy of finite-dimensional metrics for space-time surfaces characterize by the cognitive representations.

The interpretation in real context would be in terms of finite measurement resolution and the hierarchy would correspond to a hierarchy of hyper-finite factors (HFFs) [K12, K3], whose defining property is that they allow arbitrarily precise finite-dimensional approximations. What would be new is that the hierarchy of extensions of rationals would define a hierarchy of discretizations and hierarchy of HFFs.

The above list involves several unproven conjectures, which I can argue to be intuitively obvious with the experience of four decades: I cannot of course expect that a colleague reading for the first time about TGD would share these intuitions.

## 2.2 Classical TGD

Classical TGD is now rather well understood both in both  $H = M^4 \times CP_2$  and  $M^8$  pictures. Applications of classical TGD are in  $H$  picture and rather detailed phenomenology has emerged.  $M^8$  picture has led to a rather precise vision about adelic physics and to understanding of finite measurement resolution.

### 2.2.1 Classical TGD in $M^8$ picture

Classical TGD in  $M^8$  picture is discussed in [L5].

1. In  $M^8$  picture one ends to an extremely simple number theoretic construction of space-time surfaces fixing only discrete or even finite number of space-time points to obtain space-time surface for a given extension of rationals. The reason is that space-time surfaces are zero loci for  $RE(P)$  or  $IM(P)$  of octonionic polynomials obtained by continuing real polynomial with coefficients in an extension of rationals to an octonionic polynomial.

Needless to say, the hierarchy of algebraic extensions of rationals is what makes the dynamics at given level so simple. The coordinates of space-time surface as a point of WCW must be in the extension of rationals. As noticed, the points of space-time surface defining the cognitive representation determining the space-time surface serve as its natural WCW coordinates.

2. The highly non-trivial point is that no variational principle is involved with  $M^8$  construction. Therefore it seems that neither WCW metric nor Kähler function is needed. If this is the case, the exponential of Kähler function definable as action exponential does not appear in scattering amplitudes and must disappear also at  $H$ -side from the scattering amplitudes.
3. Skeptic could argue that one loses general coordinate invariance in this approach. This is not true. Linear  $M^8$  coordinates are the only possible option and forced already by symmetries. The choice octonionic and quaternionic structures fixes the linear  $M^8$  coordinates almost uniquely since time direction is associated with real octonion unit and one spatial direction to special imaginary unit defining spin quantization axis. In algebraic approach identifying space-time surface as a zero locus of  $RE(P)$  or  $IM(P)$  these coordinates define space-time coordinates highly uniquely.

Skeptic could also argue that number theoretic discretization implies reduction of the basic symmetry groups to their discrete sub-groups. This is true and one can argue that this loss of symmetry is due to the use of cognitive representations with finite resolution. Points with algebraic coordinates could be seen as a choices of representatives from a set of points, which are equivalent as far as measurement resolution is considered.

4. A physically important complication related to  $M^8$  dynamics is the possibility of different octonionic and quaternionic structures. For instance, external particles arriving into CD correspond to different octonionic and quaternionic structures in general since Lorentz boost affects the octonionic structure changing the direction of time axis, which corresponds to the real octonionic unit. In color degrees of freedom one has wave function over different quaternionic structures: essentially color partial waves labelled by color quantum numbers [K5].

One can apply Poincare transformations and color rotations (or transformation in sub-groups of these groups if one requires that the image points belong to the same extension) to the discrete cognitive representation defining space-time surface. The moduli spaces for these structures are essential for the understanding the standard Poincare and color quantum numbers and standard conservation laws in  $M^8$  picture. Also the size scales of CDs define moduli as also Lorentz boosts leaving either boundary of CD unaffected.

### 2.2.2 Classical TGD in $H$ picture

At the  $H$  side one action principle has partial differential equations and infinite number of gauge conditions associated with a sub-algebra of super-symplectic algebra selecting only extremely few preferred extremals of the action principle in terms of gauge conditions for a sub-algebra of super-symplectic algebra. This dynamics is conjectured to follow from the assumption that 6-D lift of space-time surface  $X^4$  to a  $CP_1$  bundle over  $X^4$  is twistor space of  $X^4$ . This condition requires the analog of dimensional reduction since  $S^2$  fiber is dynamically trivial.

For 6-D preferred extremals identifiable as twistor spaces of space-time surfaces the 6-D Kähler action in the product of twistor spaces of  $M^4$  and  $CP_2$  is assumed to dimensionally reduce to 4-D Kähler action plus volume term identifiable as the analog of cosmological constant term. This picture reproduces a description of scattering events highly analogous to that emerging in



$M^8$ . External particles correspond to minimal surfaces as analogs of free massless fields and all couplings disappear from the value of the action. The interior of CD corresponds to non-trivial coupling to Kähler 4-force which does not vanish. In  $M^8$  picture one has associative and non-associative regions as counterparts of these regions.

What is remarkable is that the dynamics determined by partial differential equations plus gauge conditions would be equivalent with the number theoretic dynamics determined in terms of zero loci for real or imaginary parts of octonionic polynomials.

## 2.3 Scattering amplitudes in ZEO

The construction of scattering amplitudes even at the level of principle is far from well-understood. I have discussed rather concrete proposals for the twistorial construction but the feeling is that something is still missing [K11, K19, K18, K20]. This feeling might well reflect my quite too limited mathematical understanding of twistors and experience about practical construction of the scattering amplitudes. Later I will discuss possible identification of the missing piece of puzzle.

Consider first the general picture about the construction of scattering amplitudes suggested by ZEO inspired theory of quantum measurement theory defining also a theory of consciousness.

1. The portions of space-time surfaces outside CD correspond to external particles. They satisfy associativity conditions at  $M^8$  side making possible to map them to minimal surfaces in  $H = M^4 \times CP_2$  satisfying various infinite number of gauge conditions for a sub-algebra of super-symplectic algebra isomorphic with it.

**Remark:** There is an additional condition requiring that associative tangent space or normal space contains fixed complex subspace of quaternions. It is not quite clear whether this condition can be generalized so that the distribution of these spaces is integrable.

At both sides the dynamics of external particles is in a well-defined sense critical at both sides and does not depend at all on coupling constants.

2. Inside CDs associativity conditions break down in  $M^8$  and one cannot map this spacetime region - call it  $X^4$  - to  $H$  [L5]. It is however possible to construct counterpart of  $X^4$  in  $H$  as a preferred extremal for the twistor lift of Kähler action by fixing the 3-surfaces at the boundaries of CD (boundary conditions). The dependence on couplings at the level of  $H$  would come from the vanishing conditions for classical Noether charges, which depend on coupling parameters.
3. If the two descriptions of the scattering amplitudes are equivalent, the dependence on coupling parameters in  $H$  should have a counterpart in  $M^8$ . Coupling constants making sense only at  $H$  side are expected to depend on the size scale of CD and on the extension of rationals defining the adele [L6, L7]. Coupling constants should be determined completely by the boundary values of Noether charges at the ends of space-time surface, and therefore by the 3-D ends of associative space-time regions representing external particles at  $M^8$  side. This would suggest that coupling constants are functions of the coefficients of the polynomials and the points of cognitive representation.

### 2.3.1 Zero energy ontology and the life cycle of self

ZEO meant a decisive step in the understanding of quantum TGD since it solved the basic paradox of quantum measurement problem by forcing to realize that subjective and geometric time are not the same thing [L8].

1. Both the passive boundary of CD and the members of state pairs at it are unaffected during the sequence of state reductions analogous to weak measurements (see <http://tinyurl.com/zt36hpb>) defining self as a generalized Zeno effect. The members of state pairs associated with the active boundary change and the active boundary itself drifts farther away from the passive one in the sequence of “small” state function reductions.

Also the space-time surfaces connecting passive and active boundaries change during the sequence of weak measurements. Only the 3-surfaces at the passive boundary are unaffected.

Hence the geometric past relative to the active boundary changes during the life cycle of self. In positive energy ontology (PEO) this is not possible.

2. In “big” state function reduction the roles of passive and active boundary are changed and the arrow of time identifiable as the direction in which CD grows changes. In consciousness theory “big” state function reduction corresponds to the death of self and subsequent re-incarnations as a self with an opposite arrow of geometric time.
3. In ZEO the life cycle of self corresponds to a sequence of steps. Single step begins with a unitary time evolution in which a superposition of states associated with CDs larger than the original CD emerges. Then follows the analog of weak measurement leading to a localization to a CD in the moduli space of CDs so that it has a fixed and in general larger size. A measurement of geometric time occurs and gives rise to an experience about the flow of time.

This option would allow to identify the total S-matrix as a product of the S-matrices associated with various steps in spirit with the interpretation as a generalized Zeno effect.

**Remark:** In the usual description one fixes the time interval to which one assigns the S-matrix. There is no division to steps giving rise to the experience of time flow.

4. The measurement of geometric time would be a partial measurement reducing more general unitary time evolution to a unitary time evolution in the standard sense. Can one generalize the notion of partial measurement to other observables so that one would still have unitary time evolution albeit in more restricted sense? Or should one consider giving up the unitary time evolution?

These observables should commute with the observables having the states at passive boundary as eigenstates: otherwise the state at passive boundary would change. If this picture makes sense, the “big” reduction to the opposite boundary meaning the death of self would necessarily occur when all observables commuting with the eigen observables at the passive boundary have been measured. It could of course occur already earlier.

Should one allow measurements of all observables commuting with the eigen observables at the passive boundary. This would lead to partial de-coherence of the zero energy state. In TGD inspired quantum biology this could allow to understand ageing as an unavoidable gradual loss of the quantum coherence.

### 2.3.2 More detailed interpretation of ZEO

There are several questions related to the detailed interpretation of ZEO. The intuitive picture is that inside CD representing self one has collection of sub-CDs representing sub-selves identified as mental images of self. One can loosely say, that sub-CDs represent mind. The sub-CDs are connected by on mass shell lines, which correspond to external particles - matter. Sub-CDs can also have sub-CDs and the hierarchy can have several levels.

The states at the boundaries of CD have opposite total quantum numbers. One can consider two interpretations.

1. In positive energy ontology (PEO) the notion of zero energy state could be seen only as an elegant manner to express conservation laws. This is done in QFT quite generally - also in twistor approach. Also the largest CD would have external particles emanating from its boundaries travelling to the geometric past and future. One would have however have only information about the interior of the CD possessed by conscious entity for which CD plus its sub-CDs (mental images) serve as correlates.

In this picture the arrow of time is fixed since it must be same for all sub-CDs in order to void inconsistency with the basic idea about self as generalized Zeno effect realized as a sequence of weak measurements.

2. ZEO suggest a more radical interpretation. Zero energy state defines an event. There would be the largest CD defining self and sub-CDs would correspond to mental images. There would be no external particles emanating from the boundaries of the largest CD. In this framework it becomes possible to speak about the death of self as the first state function reduction to the opposite boundary changing the roles of active and passive boundaries of self.

This picture should be consistent with what we know about arrow of time and in TGD framework with the idea that the arrow of time can also change - in particular in living matter.

1. How would the standard arrow of time emerge in ZEO? One could see the emergence of the global arrow of geometric time as a process in which the size of the largest CD increases: the sub-CDs are forced to have the same arrow of time as the largest CD and cannot make state function reductions on opposite boundary (die) independently of it. During evolution the size of the networks with the same arrow of geometric time increases and fixed arrow of geometric time is established in longer scales.
2. This picture cannot be quite correct. The applications of TGD inspired consciousness require that the mental images of self can have arrow of geometric time opposite to that of self. For instance, motor actions could be sensory perceptions in non-standard arrow of time. Memory could be communications with brain of geometric past - seeing in time direction - involving signals to geometric past requiring temporary reversals of the arrow of time at some level of self-hierarchy. Hence space-time regions with different arrows of time but forming a connected space-time surface ought to be possible.

Many-sheeted space-time means a hierarchy of space-time sheets connected by what I call wormhole contacts having Euclidian signature of the induced metric. Space-time sheets at different levels of the hierarchy are not causally connected in the sense that one cannot speak of signal propagation in the regions of Euclidian signature. This suggests that the space-time sheets connected by wormhole contacts can have different arrows of geometric time and are associated with their own CDs.

In this manner one would avoid the paradox resulting when sub-self - mental image - dies so that its passive boundary becomes active and the particles emanating from it end up to the passive boundary of CD, where no changes are allowed during the life cycle of self. If the particles emanating from time-reversed sub-self and up to boundaries of parallel CD, the problem is circumvented.

3. Wormhole contacts induce an interaction between Minkowskian space-time sheets that they connect. The interaction is not mediated by classical signals but by boundary conditions at the boundaries between Minkowskian regions and Euclidian wormhole contact. These two boundaries are light-like orbits of opposite wormhole throats (partonic 2-surfaces).

In number theoretic picture the presence of wormhole contact is reflected in the properties set of points in extension of rationals defining the cognitive representation in turn defining the space-time surface. In particular, the points associated with wormhole contact have space-like distance although they are at opposite boundaries of CD and have time-like distance in the metric of imbedding space. This kind of point pairs associated with wormhole contacts serve as a tell-tale signature for them.

### 3 The counterpart of the twistor approach in TGD

The analogs of twistor diagrams could emerge in TGD [K19, K20] in the following manner in ZEO.

1. Portions of space-time surfaces inside CDs would appear as analogs of vertices and the spacetime surfaces connecting them as analogs of propagator lines. The "lines" connecting sub-CDs would carry massless on mass shell states but possibly with complex momenta analogous to those appearing in twistor diagrams. This is true also classically at level of  $H$ : the coupling constants appearing in the action defining classical dynamics - at least Kähler coupling strength - are complex so that also conserved quantities have also imaginary parts.

**Remark:** At the level of  $M^8$  one does not have action principle and cannot speak of Noether charges. Here the conserved charges are associated with the symmetries of the moduli spaces such as the moduli spaces for octonion and quaternion structures [L5]. The identification of the classical charges in Cartan algebra at  $H$  level with the quantum numbers labeling wave functions in moduli space at  $M^8$  level could be seen as a realization of quantum classical correspondence.

2. At space-time level the vertices of twistor diagrams correspond to partonic 2-surfaces in the interior of given CD. In  $H$  description fermionic lines along the light-like orbits of partonic 2-surfaces scatter at partonic 2-surfaces. If each partonic 2-surface defining a vertex is surrounded by a sub-CD, these two views about TGD variants of twistor diagrams are unified. Sub-CD can of course contain more complex structures such as pair of wormhole contacts assignable to an elementary particle.

### 3.1 Could the classical number theoretical dynamics define the hard core of the scattering amplitudes?

The natural hope is that the simple picture about classical dynamics at the level of  $M^8$  should have similar counterpart at the level of scattering amplitudes in  $M^8$ . The above arguments suggest that the scattering diagrams correspond to CDs connected by external particle lines representing on mass shell particles. These surfaces are associative at the level of  $M^8$  and minimal surfaces at the level of  $H$ . This suggests that scattering amplitude for single CD serves as a building brick for scattering amplitudes: the rest would be “just kinematics” dictated by the enormous symmetries of WCW.

1. Everything in the construction should reduce to a hard core around which one would have integrations (or sums for number theoretic realization of finite measurement resolution) over various moduli characterizing the standard quantum numbers. Twistors for  $M^4$  and  $CP_2$  and the moduli for the choices of CDs should correspond to essentially kinematic contribution involving no genuine dynamics.
2. The scattering amplitudes should make sense in all sectors of adèle. This poses powerful constraints on them. The exponential of Kähler function reducing to action exponential can in principle appear in the description at  $H$ -side but cannot be present at  $M^8$  side. Therefore it should disappear also at the level of  $H$ .

If the scattering amplitude at the level of  $H$  is sum over contributions with the same value of the action exponential, the exponentials indeed cancel and I have proposed that this condition holds true. In perturbative quantum field theory it holds practically always and in integrable theories is exact. This would mean enormous simplification since all information about the action principle in  $H$  would appear in the vanishing conditions for the Noether charges of the subalgebra of super-symplectic algebra at the ends of the space-time surface. These Noether changes indeed depend on the action principle and thus on coupling constants.

3. Could the hard core in the construction of the scattering amplitudes be just the choice of the cognitive representation as points if  $M^8$  belonging to the algebraic extension defining the adèle and determining space-time surface in terms of octonionic polynomial inside this CD defining the interaction region?

The set of points of extension of rationals in the cognitive representation defines space-time surface and also its WCW coordinates. The restriction to a cognitive representation with given number of points in given extension of rationals would mean a reduction of WCW to a finite-dimensional sub-space.

The first wild guess is that this space is Kähler manifold with maximal symmetries - just as WCW is. A further wild guess is that these reduced WCWs are Grassmannians and correspond to those appearing in the twistor Grassmannian approach. A more general conjecture is inspired by the vision that super-symplectic gauge conditions effectively reduce the super-symplectic algebra to a Kac-Moody algebra of a finite-dimensional Lie group - perhaps belonging to ADE hierarchy. The flag manifolds associated with these Lie groups define more general homogenous spaces as candidates for the reduced WCWs.

4. One must allow the action of Galois group and this gives several options for given set  $X$  of points in algebraic extension.
  - (a) One can construct  $X^4(X)$  in terms of octonionic polynomial and construct a representation of Galois group as superposition of space-time surfaces obtained from space-time surface by the action of Galois group on  $X$  giving rise to new sets  $X_g = g(X)$ .

- (b) One can also consider the action of Galois group on  $X$  and get larger set  $Y$  of points and construct single multi-sheeted surface  $X^4(Y)$ . This surface corresponds to Planck constant  $h_{eff}/h = n$ , where  $n$  is the dimension of algebraic extension.
  - (c) One can also consider the actions of sub-groups of  $H \subset Gal$  to  $X$  to get space-time surface with  $h_{eff}/h = m$  dividing  $n$ . There are several options corresponding to representations for all sub-groups of Galois group. A hierarchy of symmetry breakings seems to be involved with unbroken symmetry associated with the largest value of  $h_{eff}/h$ .
5. In this picture the hard core would reduce to the classical number theoretical dynamics of space-time surface in  $M^8$ . The additional degrees of freedom would be due to the possibility of different octonionic and quaternionic structures and choices of size scales and Lorentz boosts and translations of CDs. The symmetries would dictate the S-matrix in the moduli degrees of freedom: the dream is that this part of the dynamics reduces to kinematics, so to say.

The discrete coupling constant evolution would be determined by the hierarchy of extensions of rationals and by the hierarchy of p-adic length scales. The cancellation of radiative corrections in the sense of sub-CDs inside CDs could be achieved by replacing coupling constant evolution with its discrete counterpart.

If this dream has something to do with reality, the construction of scattering amplitudes would reduce to their construction in moduli degrees of freedom and here the generalization of twistorial approach relying on Yangian symmetry allowing to identify scattering amplitudes as Yangian invariants might “trivialize” the situation. It will be found that the Yangian symmetry could correspond to general coordinate transformations for the reduced WCW forced by the restriction of the spacetime surfaces to those allowed by octonionic polynomials with coefficients in the extension of rationals.

### 3.2 Do loop contributions to the scattering amplitudes vanish in TGD framework?

In TGD scattering amplitudes interpreted as zero energy states would correspond at imbedding space level to collections of space-time surfaces inside CDs analogous to vertices and connected by lines defined by the space-time surfaces representing on-mass-shell particles. One would have massless particles in 8-D sense. The quaternionicity of 8-momentum leads to  $M^4 \times CP_2$  picture and  $CP_2$  twistors should replace  $E^4$  twistors of  $M^8$  approach.

#### 3.2.1 Why loop corrections should vanish?

There are several arguments suggesting that the loop contributions should vanish in TGD framework. This would give rise to a discrete coupling constant evolution analogous to a sequence of phase transitions between different critical coupling parameters. Amplitudes would be obtained as tree diagrams.

1. In ZEO it is far from clear what the basic operation defining the loop contribution could even mean. One would have zero energy state for which the members of added particle pair have opposite but momenta but the amplitude is superposition of states with varying momenta. Why should one allow zero energy states containing one particle which is not an eigenstate of momentum? This suggests that ZEO does not allow loop contributions at all: the distinction between PEO and ZEO would make itself visible in rather dramatic manner.
2. The restriction of the BCFW to tree diagrams is internally consistent since the loop term is identically vanishing in this case. The first term in the BCFW for diagram with  $l$  loops involves a factor with  $l > 0$  loops which vanishes. In  $l = 1$  case the second term is obtained from  $(n + 2, l - 1 = 0)$  diagram by generating loop but this vanishes by assumption.
3. Number theoretic vision does not favor the decomposition of the amplitude to an infinite sum of amplitudes since this is expected to lead to the emergence of transcendental numbers and functions in the amplitude in conflict with the number theoretical universality.

Loops indeed give logarithms and poly-logarithms of rational functions of external momenta in Grassmannian approach. This violates the number theoretical universality since the p-adic counterpart of logarithm exist only for the argument of form  $x = 1 + O(p)$ . This condition cannot hold true for all primes simultaneously.

Discrete coupling constant evolution suggests the vanishing of loops. One can imagine two alternative mechanisms for the vanishing of loop contributions. Either the loop contributions do not make sense at all in ZEO, or the sum of loop contributions for the critical values of coupling constants vanishes. The summing up of loop contributions to zero for critical values of couplings should happen for all values of external momenta and other quantum numbers: this does not look plausible.

### 3.2.2 General number theoretic ideas about coupling constant evolution

The discrete coupling constant evolution would be associated with the scale hierarchy for CDs and the hierarchy of extensions of rationals.

1. Discrete p-adic coupling constant evolution would naturally correspond to the dependence of coupling constants on the size of CD. For instance, I have considered a concrete but rather ad hoc proposal for the evolution of Kähler couplings strength based on the zeros of Riemann zeta [L2]. Number theoretical universality suggests that the size scale of CD identified as the temporal distance between the tips of CD using suitable multiple of  $CP_2$  length scale as a length unit is integer, call it  $l$ . The prime factors of the integer could correspond to preferred p-adic primes for given CD.
2. I have also proposed that the so called ramified primes of the extension of rationals correspond to the physically preferred primes. Ramification is algebraically analogous to criticality in the sense that two roots understood in very general sense co-incide at criticality. Could the primes appearing as factors of  $l$  be ramified primes of extension? This would give strong correlation between the algebraic extension and the size scale of CD.

In quantum field theories coupling constants depend in good approximation logarithmically on mass scale, which would be in the case of p-adic coupling constant evolution replaced with an integer  $n$  characterizing the size scale of CD or perhaps the collection of prime factors of  $n$  (note that one cannot exclude rational numbers as size scales). Coupling constant evolution could also depend on the size of extension of rationals characterized by its order and Galois group.

In both cases one expects approximate logarithmic dependence and the challenge is to define “number theoretic logarithm” as a rational number valued function making thus sense also for p-adic number fields as required by the number theoretical universality.

#### 1. Coupling constant evolution with respect to CD size scale

Consider first the coupling constant as a function of the length scale  $l_{CD}(n)/l_{CD}(1) = n$ .

1. The number  $\pi(n)$  of primes  $p \leq n$  behaves approximately as  $\pi(n) = n/\log(n)$ . This suggests the definition of what might be called “number theoretic logarithm” as  $Log(n) \equiv n/\pi(n)$ . Also iterated logarithms such  $\log(\log(x))$  appearing in coupling constant evolution would have number theoretic generalization.
2. If the p-adic variant of  $Log(n)$  is mapped to its real counterpart by canonical identification involving the replacement  $p \rightarrow 1/p$ , the behavior can very different from the ordinary logarithm.  $Log(n)$  increases however very slowly so that in the generic case one can expect  $Log(n) < p_{max}$ , where  $p_{max}$  is the largest prime factor of  $n$ , so that there would be no dependence on  $p$  for  $p_{max}$  and the image under canonical identification would be number theoretically universal.

For  $n = p^k$ , where  $p$  is small prime the situation changes since  $Log(n)$  can be larger than small prime  $p$ . Primes  $p$  near primes powers of 2 and perhaps also primes near powers of 3 and 5 - at least - seem to be physically special. For instance, for Mersenne prime  $M_k = 2^k - 1$  there would be dramatic change in the step  $M_k \rightarrow M_k + 1 = 2^k$ , which might relate to its special physical role.

3. One can consider also the analog of  $Log(n)$  as

$$Log(n) = \sum_p k_p Log(p) ,$$

where  $p^{k_i}$  is a factor of  $n$ .  $Log(n)$  would be sum of number theoretic analogs for primes factors and carry information about them.

One can extend the definition of  $Log(x)$  to the rational values  $x = m/n$  of the argument. The logarithm  $Log_b(n)$  in base  $b = r/s$  can be defined as  $Log_b(x) = Log(x)/Log(b)$ .

4. For  $p \in \{2, 3, 5\}$  one has  $Log(p) > log(p)$ , where for larger primes one has  $Log(p) < log(p)$ . One has  $Log(2) = 2 > log(2) = .693\dots$ ,  $Log(3) = 3k/2 > log(3) = 1.099$ ,  $Log(5) = 5/3 = 1.666\dots > log(5) = 1.609$ . For  $p = 7$  one has  $Log(7) = 7/4 \simeq 1.75 < log(7) \simeq 1.946$ . Hence these primes and CD size scales  $n$  involving large powers of  $p \in \{2, 3, 5\}$  ought to be physically special as indeed conjectured on basis of p-adic calculations and some observations related to music and biological evolution [K7, K8, K9, K17].

In particular, for Mersenne primes  $M_k = 2^k - 1$  one would have  $Log(M_k) \simeq klog(2)$  for large enough  $k$ . For  $Log(2^k)$  one would have  $k \times Log(2) = 2k > log(2^k) = klog(2)$ : there would be sudden increase in the value of  $Log(n)$  at  $n = M_k$ . This jump in p-adic length scale evolution might relate to the very special physical role of Mersenne primes strongly suggested by p-adic mass calculations [K5].

5. One can wonder whether one could replace the  $log(p)$  appearing as a unit in p-adic negentropy [K6] with a rational unit  $Log(p) = p/\pi(p)$  to gain number theoretical universality? One could therefore interpret the p-adic negentropy as real or p-adic number for some prime. Interestingly,  $|Log(p)|_p = 1/p$  approaches zero for large primes  $p$  (eye cannot see itself!) whereas  $|Log(p)|_q = 1/|\pi(p)|_q$  has large values for the prime power factors  $q^r$  of  $\pi(p)$ .

2. *The dependence of  $1/\alpha_K$  on the extension of rationals*

Consider next the dependence on the extension of rationals. The natural algebraization of the problem is to consider the Galois group of the extension.

1. Consider first the counterparts of primes and prime factorization for groups. The counterparts of primes are simple groups, which do not have normal subgroups  $H$  satisfying  $gH = Hg$  implying invariance under automorphisms of  $G$ . Simple groups have no decomposition to a product of sub-groups. If the group has normal subgroup  $H$ , it can be decomposed to a product  $H \times G/H$  and any finite group can be decomposed to a product of simple groups.

All simple finite groups have been classified (see <http://tinyurl.com/jn44bxe>). There are cyclic groups, alternating groups, 16 families of simple groups of Lie type, 26 sporadic groups. This includes 20 quotients  $G/H$  by a normal subgroup of monster group and 6 groups which for some reason are referred to as pariahs.

2. Suppose that finite groups can be ordered so that one can assign number  $N(G)$  to group  $G$ . The roughest ordering criterion is based on  $ord(G)$ . For given order  $ord(G) = n$  one has all groups, which are products of cyclic groups associated with prime factors of  $n$  plus products involving non-Abelian groups for which the order is not prime.  $N(G) > ord(G)$  thus holds true. For groups with the same order one should have additional ordering criteria, which could relate to the complexity of the group. The number of simple factors would serve as an additional ordering criterion.

If its possible to define  $N(G)$  in a natural manner then for given  $G$  one can define the number  $\pi_1(N(G))$  of simple groups (analogs of primes) not larger than  $G$ . The first guess is that that the number  $\pi_1(N(G))$  varies slowly as a function of  $G$ . Since  $Z_i$  is simple group, one has  $\pi_1(N(G)) \geq \pi(N(G))$ .

3. One can consider two definitions of number theoretic logarithm, call it  $Log_1$ .

$$\begin{aligned}
 a) \quad \text{Log}_1(N(G)) &= \frac{N(G)}{\pi_1(N(G))} \quad , \\
 b) \quad \text{Log}_1(G) &= \sum_i k_i \text{Log}_1(N(G_i)) \quad , \quad \text{Log}_1(N(G_i)) = \frac{N(G_i)}{\pi_1(N(G_i))} \quad .
 \end{aligned}
 \tag{3.1}$$

Option a) does not provide information about the decomposition of  $G$  to a product of simple factors. For Option b) one decomposes  $G$  to a product of simple groups  $G_i$ :  $G = \prod_i G_i^{k_i}$  and defines the logarithm as Option b) so that it carries information about the simple factors of  $G$ .

4. One could organize the groups with the same order to same equivalence class. In this case the above definitions would give

$$\begin{aligned}
 a) \quad \text{Log}_1(\text{ord}(G)) &= \frac{\text{ord}(G)}{\pi_1(\text{ord}(G))} < \text{Log}(\text{ord}(G)) \quad , \\
 b) \quad \text{Log}_1(\text{ord}(G)) &= \sum_i k_i \text{Log}(\text{ord}(G_i)) \quad , \quad \text{Log}_1(\text{ord}(G_i)) = \frac{\text{ord}(G_i)}{\pi_1(\text{ord}(G_i))} \quad .
 \end{aligned}
 \tag{3.2}$$

Besides groups with prime orders there are non-Abelian groups with non-prime orders. The occurrence of same order for two non-isomorphic finite simple groups is very rare (see <http://tinyurl.com/ydd6uomb>). This would suggest that one has  $\pi_1(\text{ord}(G)) < \text{ord}(G)$  so that  $\text{Log}_1(\text{ord}(G))/\text{ord}(G) < 1$  would be true.

5. For orders  $n(G) \in \{2, 3, 5\}$  one has  $\text{Log}_1(n(G)) = \text{Log}(n(G)) > \log(n(G))$  so that the orders  $n(G)$  involving large factors of  $p \in \{2, 3, 5\}$  would be special also for the extensions of rationals.  $S_3$  with order 6 is the first non-abelian simple group. One has  $\pi(S_3) = 4$  giving  $\text{Log}(6) = 6/4 = 1.5 < \log(6) = 1.79$  so that  $S_3$  is different from the simple groups below it.

To sum up, number theoretic logarithm could provide answer to the long-standing question what makes Mersenne primes and also other small primes so special.

### 3.2.3 Considerations related to coupling constant evolution and Riemann zeta

I have made several number theoretic speculations related to the possible role of zeros of Riemann zeta in coupling constant evolution. The basic problem is that it is not even known whether the zeros of zeta are rationals, algebraic numbers or genuine transcendentals or belong to all these categories. Also the question whether number theoretic analogs of  $\zeta$  defined for p-adic number fields could make sense in some sense is interesting.

1. Is number theoretic analog of  $\zeta$  possible using  $\text{Log}(p)$  instead of  $\log(p)$ ?

The definition of  $\text{Log}(n)$  based on factorization  $\text{Log}(n) \equiv \sum_p k_p \text{Log}(p)$  allows to define the number theoretic version of Riemann Zeta  $\zeta(s) = \sum n^{-s}$  via the replacement  $n^{-s} = \exp(-\log(n)s) \rightarrow \exp(-\text{Log}(n)s)$ .

1. In suitable region of plane number-theoretic Zeta would have the usual decomposition to factors via the replacement  $1/(1 - p^{-s}) \rightarrow 1/(1 - \exp(-\text{Log}(p)s))$ . p-Adically this makes sense for  $s = O(p)$  and thus only for a finite number of primes  $p$  for positive integer valued  $s$ : one obtains kind of cut-off zeta. Number theoretic zeta would be sensitive only to a finite number of prime factors of integer  $n$ .
2. This might relate to the strong physical indications that only a finite number of cognitive representations characterized by p-adic primes are present in given quantum state: the ramified primes for the extension are excellent candidates for these p-adic primes. The size scale  $n$  of CD could also have decomposition to a product of powers of ramified primes. The finiteness of cognition conforms with the cutoff: for given CD size  $n$  and extension of rationals the p-adic primes labelling cognitive representations would be fixed.



3. One can expand the regions of converge to larger p-adic norms by introducing an extension of p-adics containing  $e$  and some of its roots ( $e^p$  is automatically a p-adic number). By introducing roots of unity, one can define the phase factor  $\exp(-i\text{Log}(n)\text{Im}(s))$  for suitable values of  $\text{Im}(s)$ . Clearly,  $\exp(-ip\text{Im}(s))/\pi(p)$  must be in the extension used for all primes  $p$  involved. One must therefore introduce prime roots  $\exp(i/\pi(p))$  for primes appearing in cutoff. To define the number theoretic zeta for all p-adic integer values of  $\text{Re}(s)$  and all integer values of  $\text{Im}(s)$ , one should allow all roots of unity ( $e^{i2\pi/n}$ ) and all roots  $e^{1/n}$ : this requires infinite-dimensional extension.
4. One can thus define a hierarchy of cutoffs of zeta: for this the factorization of Zeta to a finite number of "prime factors" takes place in genuine sense, and the points  $\text{Im}(s) = ik\pi(p)$  give rise to poles of the cutoff zeta as poles of prime factors. Cutoff zeta converges to zero for  $\text{Re}(s) \rightarrow \infty$  and exists along angles corresponding to allowed roots of unity. Cutoff zeta diverges for  $(\text{Re}(s) = 0, \text{Im}(s) = ik\pi(p))$  for the primes  $p$  appearing in it.

**Remark:** One could modify also the definition of  $\zeta$  for complex numbers by replacing  $\exp(\log(n)s)$  with  $\exp(\text{Log}(n)s)$  with  $\text{Log}(n) = \sum_p k_p \text{Log}(p)$  to get the prime factorization formula. I will refer to this variant of zeta as modified zeta ( $\tilde{\zeta}$ ) below.  $\tilde{\zeta}$  would carry explicit number theoretic information via the dependence of its "prime factors"  $1/(1 - \exp(-\text{Log}(p)s))$ .

2. Could the values of  $1/\alpha_K$  be given as zeros of  $\zeta$  or of  $\tilde{\zeta}$

In [L2] I have discussed the possibility that the zeros  $s = 1/2 + iy$  of Riemann zeta at critical line correspond to the values of complex valued Kähler coupling strength  $\alpha_K$ :  $s = i/\alpha_K$ . The assumption that  $p^{iy}$  is root of unity for some combinations of  $p$  and  $y$  [ $\log(p)y = (r/s)2\pi$ ] was made. This does not allow  $s$  to be complex rational. If the exponent of Kähler action disappears from the scattering amplitudes as  $M^8 - H$  duality requires, one could assume that  $s$  has rational values but also algebraic values are allowed.

1. If one combines the proposed idea about the Log-arithmetic dependence of the coupling constants on the size of CD and algebraic extension with  $s = i/\alpha_K$  hypothesis, one cannot avoid the conjecture that the zeros of zeta are complex rationals. It is not known whether this is the case or not. The rationality would not have any strong implications for number theory but the existence irrational roots would have (see <http://tinyurl.com/y8bbnhe3>). Interestingly, the rationality of the roots would have very powerful physical implications if TGD inspired number theoretical conjectures are accepted.

The argument discussed below however shows that complex rational roots of zeta are not favored by the observations [A2] about the Fourier transform for the characteristic function for the zeros of zeta. Rather, the findings suggest that the imaginary parts [L1] should be rational multiples of  $2\pi$ , which does not conform with the vision that  $1/\alpha_K$  is algebraic number. The replacement of  $\log(p)$  with  $\text{Log}(p)$  and of  $2\pi$  with its natural p-adic approximation in an extension allowing roots of unity however allows  $1/\alpha_K$  to be an algebraic number. Could the spectrum of  $1/\alpha_K$  correspond to the roots of  $\zeta$  or of  $\tilde{\zeta}$ ?

2. A further conjecture discussed in [L2] was that there is 1-1 correspondence between primes  $p \simeq 2^k$ ,  $k$  prime, and zeros of zeta so that there would be an order preserving map  $k \rightarrow s_k$ . The support for the conjecture was the predicted rather reasonable coupling constant evolution for  $\alpha_K$ . Primes near powers of 2 could be physically special because  $\text{Log}(n)$  decomposes to sum of  $\text{Log}(p)$ :s and would increase dramatically at  $n = 2^k$  slightly above them.

In an attempt to understand why just prime values of  $k$  are physically special, I have proposed that k-adic length scales correspond to the size scales of wormhole contacts whereas particle space-time sheets would correspond to  $p \simeq 2^k$ . Could the logarithmic relation between  $L_p$  and  $L_k$  correspond to logarithmic relation between  $p$  and  $\pi(p)$  in case that  $\pi(p)$  is prime and could this condition select the preferred p-adic primes  $p$ ?

3. The argument of Dyson for the Fourier transform of the characteristic function for the set of zeros of  $\zeta$

Consider now the argument suggesting that the roots of zeta cannot be complex rationals. On basis of numerical evidence Dyson [A2] (<http://tinyurl.com/hjbfsvv>) has conjectured that the Fourier transform for the characteristic function for the critical zeros of zeta consists of multiples of logarithms  $\log(p)$  of primes so that one could regard zeros as one-dimensional quasi-crystal.

This hypothesis makes sense if the zeros of zeta decompose into disjoint sets such that each set corresponds to its own prime (and its powers) and one has  $p^{iy} = U_{m/n} = \exp(i2\pi m/n)$  (see the appendix of [L1]). This hypothesis is also motivated by number theoretical universality [K16, L6].

1. One can re-write the discrete Fourier transform over zeros of  $\zeta$  at critical line as

$$f(x) = \sum_y \exp(ixy) \quad , \quad y = \text{Im}(s) \quad .$$

The alternative form reads as

$$f(u) = \sum_s u^{iy} \quad , \quad u = \exp(x) \quad .$$

$f(u)$  is located at powers  $p^n$  of primes defining ideals in the set of integers.

For  $y = p^n$  one would have  $p^{iny} = \exp(in\log(p)y)$ . Note that  $k = n\log(p)$  is analogous to a wave vector. If  $\exp(in\log(p)y)$  is root of unity as proposed earlier for some combinations of  $p$  and  $y$ , the Fourier transform becomes a sum over roots of unity for these combinations: this could make possible constructive interference for the roots of unity, which are same or at least have the same sign. For given  $p$  there should be several values of  $y(p)$  with nearly the same value of  $\exp(in\log(p)y(p))$  whereas other values of  $y$  would interfere destructively.

For general values  $y = x^n$   $x \neq p$  the sum would not be over roots of unity and constructive interference is not expected. Therefore the peaking at powers of  $p$  could take place. This picture does not support the hypothesis that zeros of zeta are complex rational numbers so that the values of  $1/\alpha_K$  correspond to zeros of zeta and would be therefore complex rationals as the simplest view about coupling constant evolution would suggest.

**Remark:** Mumford has argued (<http://tinyurl.com/zemw27o>) that the Fourier transform should include also the trivial zeros at  $s = -2, -4, -6...$  giving and exponentially small contributions and providing a slowly varying background to the Fourier transform.

2. What if one replaces  $\log(p)$  with  $\text{Log}(p) = p/\pi(p)$ , which is rational and thus  $\zeta$  with  $\tilde{\zeta}$ ? For large enough values of  $p$   $\text{Log}(p) \simeq \log(p)$  finite computational accuracy does not allow distinguish  $\text{Log}(p)$  from  $\log(p)$ . For  $\text{Log}(p)$  one could thus understand the finding in terms of constructive interference for the roots of unity if the roots of zeta are of form  $s = 1/2 + i(m/n)2\pi$ . The value of  $y$  cannot be rational number and  $1/\alpha_K$  would have real part equal to  $y$  proportional to  $2\pi$  which would require infinite-D extension of rationals. In p-adic sectors infinite-D extension does not conform with the finiteness of cognition.

**Remark:** It is possible to check by numerical calculations whether the locus of complex zeros of  $\tilde{\zeta}$  is at line  $\text{Res}(2) = 1/2$ . If so, then Fourier transform would make sense. One can also check whether the peaks at  $n\log(p)$  are shifted to  $n\text{Log}(p)$ : for  $p = 2$  one would have  $\text{Log}(2) = 2 > \log(2)$ . The positions of peaks should shift to the right for  $p = 2, 3, 5$  and to the left for  $p > 5$ . This should be easy to check by numerical calculations.

3. Numerical calculations have however finite accuracy, and allow also the possibility that  $y$  is algebraic number approximating rational multiple of  $2\pi$  in some natural manner. In p-adic sectors would obtain the spectrum of  $y$  and  $1/\alpha_K$  as algebraic numbers by replacing  $2\pi$  in the formula  $is = \alpha_K = i/2 + q \times 2\pi$ ,  $q = r/s$ , with its approximate value:

$$2\pi \rightarrow \sin(2\pi/n)n = i \frac{n}{2} (\exp(i2\pi/n) - \exp(-i2\pi/n))$$

for an extension of rationals containing  $n$ :th of unity. Maximum value of  $n$  would give the best approximation. This approximation performed by fundamental physics should appear in

the number theoretic scattering amplitudes in the expressions for  $1/\alpha_K$  to make it algebraic number.

$y$  can be approximated in the same manner in  $p$ -adic sectors and a natural guess is that  $n = p$  defines the maximal root of unity as  $\exp(i2\pi/p)$ . The phase  $\exp(i\log(p)y)$  for  $y = q\sin(2\pi/n(y))$ ,  $q = r/s$ , is replaced with the approximation induced by  $\log(p) \rightarrow \text{Log}(p)$  and  $2\pi \rightarrow \sin(2\pi/n)n$  giving

$$\exp(i\log(p)y) \rightarrow \exp(iq(y)\sin(2\pi/n(y))\frac{p}{\pi(p)}) .$$

If  $s$  in  $q = r/s$  does not contain higher powers of  $p$ , the exponent exists  $p$ -adically for this extension and can be expanded in positive powers of  $p$  as

$$\sum_n i^n q^n \sin(2\pi/p)^n (p/\pi(p))^n .$$

This makes sense  $p$ -adically.

Also the actual complex roots of  $\zeta$  could be algebraic numbers:

$$s = i/2 + q \times \sin\left(\frac{2\pi}{n(y)}\right)n(y) .$$

If the proposed correlation between  $p$ -adic primes  $p \simeq 2^k$ ,  $k$  prime and zeros of zeta predicting a reasonable coupling constant evolution for  $1/\alpha_K$  is true, one can have naturally,  $n(y) = p(y)$ , where  $p$  is the  $p$ -adic prime associated with  $y$ : the accuracy in angle measurement would increase with the size scale of CD. For given  $p$  there could be several roots  $y$  with same  $p(y)$  but different  $q(y)$  giving same phases or at least phases with same sign of real part.

Whether the roots of  $\tilde{\zeta}$  are algebraic numbers and at critical line  $\text{Re}(s) = 1/2$  is an interesting question.

**Remark:** This picture allows many variants. For instance, if one assumes standard zeta, one could consider the possibility that the roots  $y_p$  associated with  $p$  and giving rise to constructive interference are of form  $y = q \times (\text{Log}(p)/\log(p)) \times \sin(2\pi/p)p$ ,  $q = r/s$ .

4. Could functional equation and Riemann hypothesis generalize?

It is interesting to list the elementary properties of the  $\tilde{\zeta}$  before trying to answer to the questions of the title.

1. The replacement  $\log(n) \rightarrow \text{Log}(n) \equiv \sum_p k_p \text{Log}(p)$  implies that  $\tilde{\zeta}$  codes explicitly number theoretic information. Note that  $\text{Log}(n)$  satisfies the crucial identity  $\text{Log}(mn) = \text{Log}(m) + \text{Log}(n)$ .  $\tilde{\zeta}$  is an analog of partition function with rational number valued  $\text{Log}(n)$  taking the role of energy and  $1/s$  that of a complex temperature. In ZEO this partition function like entity could be associated with zero energy state as a “square root” of thermodynamical partition function: in this case complex temperatures are possible.  $|\tilde{\zeta}|^2$  would be the analog of ordinary partition function.
2. Reduction of  $\tilde{\zeta}$  to a product of “prime factors”  $1/[1 - \exp(-\text{Log}(p)s)]$  holds true by  $\text{Log}(n) \equiv \sum_p k_p \text{Log}(p)$ ,  $\text{Log}(p) = p/\pi(p)$ .
3.  $\tilde{\zeta}$  is a combination of exponentials  $\exp(-\text{Log}(n)s)$ , which converge for  $\text{Re}(s) > 0$ . For  $\zeta$  one has exponentials  $\exp(-\log(n)s)$ , which also converge for  $\text{Re}(s) > 0$ : the sum  $\sum n^{-s}$  does not however converge in the region  $\text{Re}(s) < 1$ . Presumably  $\tilde{\zeta}$  fails to converge for  $\text{Re}(s) \leq 1$ . The behavior of terms  $\exp(-\text{Log}(n)s)$  for large values of  $n$  is very similar to that in  $\zeta$ .
4. One can express  $\zeta$  o in terms of  $\eta$  function defined as

$$\eta(s) = \sum (-1)^n n^{-s} .$$

The powers  $(-1)^n$  guarantee that  $\eta$  converges (albeit not absolutely) inside the critical strip  $0 < s < 1$ .

By using a decomposition of integers to odd and even ones, one can express  $\zeta$  in terms of  $\eta$ :

$$\zeta = \frac{\eta(s)}{(-1 + 2^{-s+1})} .$$

This definition converges inside critical strip. Note the pole at  $s = 1$  coming from the factor.

One can define also  $\tilde{\eta}$ :

$$\tilde{\eta}(s) = \sum (-1)^n e^{-\text{Log}(n)s} .$$

The formula relating  $\tilde{\zeta}$  and  $\tilde{\eta}$  generalizes:  $2^{-s}$  is replaced with  $\exp(-2s)$  ( $\text{Log}(2) = 2$ ):

$$\tilde{\zeta} = \frac{\tilde{\eta}(s)}{-1 + 2\exp^{-2s}} .$$

This definition  $\tilde{\zeta}$  converges in the critical strip  $\text{Re}(s) \in (0, 1)$  and also for  $\text{Re}(s) > 1$ .  $\tilde{\zeta}(1-s)$  converges for  $\text{Re}(s) < 1$  so that in  $\tilde{\eta}$  representation both converge.

Note however that the poles of  $\zeta$  at  $s = 1$  has shifted to that at  $s = \text{log}(2)/2$  and is below  $\text{Re}(s) = 1/2$  line. If a symmetrically positioned pole at  $s = 1 - \text{log}(2)/2$  is not present in  $\tilde{\eta}$ , functional equation cannot be true.

5.  $\text{Log}(n)$  approaches  $\log(n)$  for integers  $n$  not containing small prime factors  $p$  for which  $\pi(n)$  differs strongly from  $p/\log(p)$ . This suggests that allowing only terms  $\exp(-\text{Log}(n)s)$  in the sum defining  $\tilde{\zeta}$  not divisible by primes  $p < p_{max}$  might give a cutoff  $\tilde{\zeta}^{cut, p_{max}}(s)$  behaving very much like  $\zeta$  from which “prime factors”  $1/(1 - \exp(-\text{Log}(p)s))$ ,  $p < p_{max}$  are dropped of. This is just division of  $\tilde{\zeta}$  by these factors and at least formally, this does not affect the zeros of  $\tilde{\zeta}$ . Arbitrary number of factors can be dropped. Could this mean that  $\tilde{\zeta}^{cut}$  has same or very nearly same zeros as  $\zeta$  at critical line? This sounds paradoxical and might reflect my sloppy thinking: maybe the lack of the absolute implies that the conclusion is incorrect.

The key questions are whether  $\tilde{\zeta}$  allows a generalization of the functional equation  $\xi(s) = \xi(1-s)$  with  $\xi(s) = \frac{1}{2}s(s-1)\Gamma(s/2)\pi^{-s/2}\zeta(s)$  and whether Riemann hypothesis generalizes. The derivation of the functional equation is quite a tricky task and involves integral representation of  $\zeta$ .

1. One can start from the integral representation of  $\zeta$  true for  $s > 0$ .

$$\zeta(s) = \frac{1}{(1 - 2^{1-s})\Gamma(s)} \int_0^\infty \frac{t^{s-1}}{e^t + 1} dt , \text{Re}(s) > 0 .$$

deducible from the expression in terms of  $\eta(s)$ . The factor  $1/(1 + e^t)$  can be expanded in geometric series  $1/(1 + e^t) = \sum (-1)^n \exp(nt)$  converging inside the critical strip. One formally performs the integrations by taking  $nt$  as an integration variable. The integral gives the result  $\sum (-1)^n / n^s \Gamma(s)$ .

The generalization of this would be obtained by a generalization of geometric series:

$$1/(1 + e^t) = \sum (-1)^n \exp(nt) \rightarrow \sum (-1)^n e^{\exp(\text{Log}(n))t}$$

in the integral representation. This would formally give  $\tilde{\zeta}$ : the only difference is that one takes  $u = \exp(\text{Log}(n))t$  as integration variable.

One could try to prove the functional equation by using this representation. One proof (see <http://tinyurl.com/yak93hyr>) starts from the alternative expression of  $\zeta$  as

$$\zeta(s) = \frac{1}{\Gamma(s)} \int_1^\infty \frac{t^{s-1}}{e^t - 1} dt , \text{Re}(s) > 1 .$$

One modifies the integration contour to a contour C coming from  $+\infty$  above positive real axis, circling the origin and returning back to  $+\infty$  below the real axes to get a modified representation of  $\zeta$ :

$$\zeta(s) = \frac{1}{2i \sin(\pi s) \Gamma(s)} \int_1^\infty \frac{(-w)^{s-1}}{e^w - 1} dw, \quad \text{Re}(s) > 1.$$

One modifies the C further so that the origin is circled around a square with vertices at  $\pm(2n + 1)\pi$  and  $\pm i(2n + 1)\pi$ .

One calculates the integral the integral along C as a residue integral. The poles of the integrand proportional to  $1/(1 - e^t)$  are at imaginary axis and correspond to  $w = ir2\pi$ ,  $r \in Z$ . The residue integral gives the other side of the functional equation.

2. Could one generalize this representation to the recent case? One must generalize the geometric series defined by  $1/(e^w - 1)$  to  $-\sum e^{\exp(\text{Log}(n))w}$ . The problem is that one has only a generalization of the geometric series and not closed form for the counterpart of  $1/(\exp(w)-1)$  so that one does not know what the poles are. The naive guess is that one could compute the residue integrals term by term in the sum over  $n$ . An equally naive guess would be that for the poles the factors in the sum are equal to unity as they would be for Riemann zeta. This would give for the poles of  $n$ :th term the guess  $w_{n,r} = r2\pi/\exp(\text{Log}(n))$ ,  $r \in Z$ . This does not however allow to deduce the residue at poles. Note that the poles of  $\tilde{\eta}$  at  $s = \log(2)/2$  suggests that functional equation is not true.

There is however no need for a functional equation if one is only interested in  $F(s) \equiv \tilde{\zeta}(s) + \tilde{\zeta}(1 - s)$  at the critical line! Also the analog of Riemann hypothesis follows naturally!

1. In the representation using  $\tilde{\eta}$   $F(s)$  converges at critical stripe and is *real(!)* at the critical line  $\text{Re}(s) = 1/2$  as follows from the fact that  $1 - s = \bar{s}$  for  $\text{Re}(s) = 1/2$ ! Hence  $F(s)$  is expected to have a large number of zeros at critical line. Presumably their number is infinite, since  $F(s)^{\text{cut}, p_{\text{max}}}$  approaches  $2\zeta^{\text{cut}, p_{\text{max}}}$  for large enough  $p_{\text{max}}$  at critical line.
2. One can define a different kind of cutoff of  $\tilde{\zeta}$  for given  $n_{\text{max}}$ :  $n < n_{\text{max}}$  in the sum over  $e^{-\text{Log}(n)s}$ . Call this cutoff  $\tilde{\zeta}^{\text{cut}, n_{\text{max}}}$ . This cutoff must be distinguished from the cutoff  $\tilde{\zeta}^{\text{cut}, p_{\text{max}}}$  obtained by dropping the “prime factors” with  $p < p_{\text{max}}$ . The terms in the cutoff are of the form  $u^{\sum k_p p/\pi(p)}$ ,  $u = \exp(-s)$ . It is analogous to a polynomial but with fractional powers of  $u$ . It can be made a polynomial by a change of variable  $u \rightarrow v = \exp(-s/a)$ , where  $a$  is the product of all  $\pi(p)$ :s associated with all the primes involved with the integers  $n < n_{\text{max}}$ .

One could solve numerically the zeros of  $\zeta(s) + \zeta(\bar{s})$  using program modules calculating  $\pi(p)$  for a given  $p$  and roots of a complex polynomial in given order. One can check whether also all zeros of  $\zeta(\bar{s}) + \zeta(s)$  might reside at critical line.

3. One can define also  $F(s)^{\text{cut}, n_{\text{max}}}$  to be distinguished from  $F(s)^{\text{cut}, p_{\text{max}}}$ . It reduces to a sum of terms  $\exp(-\text{Log}(n)/2) \cos(-\text{Log}(n)y)$  at critical line,  $n < n_{\text{max}}$ . Cosines come from roots of unity.  $F(s)$  function is not sum of rational powers of  $\exp(-iy)$  unlike  $\zeta(s)$ . The existence of zero could be shown by showing that the sign of this function varies as function of  $y$ . The functions  $\cos(-\text{Log}(n)y)$  have period  $\Delta y = 2\pi/\text{Log}(n)$ . For small values of  $n$  the exponential terms  $\exp(-\text{Log}(n)/2)$  are largest so that they dominate. For them the periods  $\Delta y$  are smallest so that one expected that the sign of both  $F(s)$  and  $F(s)^{\text{cut}, n_{\text{max}}}$  varies and forces the presence of zeros.

One could perhaps interpret the system as quantum critical system. The rather large rapidly varying oscillatory terms with  $n < n_{\text{max}}$  with small  $\text{Log}(n)$  give a periodic infinite set of approximate roots and the exponentially smaller slowly varying higher terms induce small perturbations of this periodic structure. The slowly varying terms with large  $\text{Log}(n)$  become however large near the  $\text{Im}(s) = 0$  so that here the there effect is large and destroys the period structure badly for small root of  $\hat{\zeta}$ .

### 3.2.4 Is the vanishing of the loop corrections consistent with unitarity?

Skeptic could argue that the vanishing of loop corrections is not consistent with unitarity. The following argument however shows that the fact that momenta in TGD framework are 8-D light-like momenta could save the situation. If not only single particle states but also *many-particle states* have light-like 8-momenta, the discontinuity of the amplitude at pole  $P^2(M^8) = 0$  implies the discontinuity of the amplitude as function of  $s \equiv P^2(M^4)$  along  $s$ -axis.

Minkowskian contribution to mass squared would essentially the sum of conformal (stringy) contribution from vibrational degrees of freedom and color contribution from  $CP_2$  degrees of freedom. This suggests a weak form of color confinement: many-particle states could have vanishing color hyper charge and isospin but the eigenvalue value of color Casimir operator would be non-vanishing.

To get more concrete view about the situation the reader is encouraged to study the slides of Jaroslav Trnka explaining BCFW recursion formula [B5] (see <http://tinyurl.com/pqjzffj>) or the article [B3] of Elvang and Huang (see <http://tinyurl.com/y9rhbzhk>).

1. Unitarity condition  $SS^\dagger = Id$  for S-matrix  $S = 1 + iT$  gives  $i(T - T^\dagger) = TT^\dagger$ . For forward scattering the physical interpretation is that the discontinuity of  $-2Im(T) = i(T - T^\dagger)$  in forward scattering as a function of total mass  $s$  above kinematical threshold along real axis is essentially the total scattering rate.
2. For a given tree amplitude, which is rational function, one replaces external momenta  $p_i$  with  $\hat{p}_i = p_i + zr_i$ .  $r_i$  real, light-like and orthogonal to each other and their sum vanishes. This gives on mass shell scattering amplitude with complex light-like momenta satisfying conservation conditions.
3. One can consider any non-trivial subset  $I$  of momenta and for this set one has  $\hat{P}_I^2 = P_i^2 + 2zP \cdot R_I$ , where one has  $P_I = \sum_i p_i$  and  $R_I = \sum_i r_i$ . This gives

$$\hat{P}_I^2 = -P_I^2 \frac{(z - z_I)}{z_I} \quad , \quad z_I = \frac{P_I^2}{2P_I \cdot R_I} \quad .$$

The poles of the modified amplitude  $\hat{A}_n(z)$  come from the propagators at  $\hat{P}_I^2 = 0$  and correspond to the points  $z = z_I$ .

4. From the modified scattering amplitude  $\hat{A}_n(z)$  one can obtain the original scattering amplitude by performing a residue integral for  $\hat{A}_n(z)/z$  along a curve enclosing the poles  $z_I$ . This gives

$$A_n = \hat{A}_n(z=0) + \sum_{z_I} Res_{z=z_I} \left( \frac{\hat{A}_n(z)}{z} \right) + B_n \quad .$$

$B_n$  comes from the possible pole at  $z = \infty$  and is often assumed to vanish. If so, the amplitude factorizes into a sum of products

$$Res_{z=z_I} \frac{\hat{A}_n(z)}{z} = \sum_I \hat{A}_L(z_I) \frac{1}{P_I^2} \hat{A}_R(z_I) \quad .$$

The amplitudes appearing in the product are for modified complex momenta.

The vanishing of loop corrections thus implies that the product terms  $\hat{A}_L(1/P^2)\hat{A}_R$  in the BCFW formula give rational functions having no cuts just as the number theoretical vision demands. The discontinuities of the imaginary part of the amplitude are at poles and reduce to the products  $\hat{A}_L\hat{A}_R$  with complex on-mass-shell light-like momenta as unitarity demands.

For forward scattering the discontinuity would be essentially positive definite total scattering rate. It would be however non-vanishing only at  $P^2 = 0$  so that scattering rate could be non-vanishing only for  $P^2 = 0$ ! This does not make sense in 4-D physics. Is it possible to overcome this difficulty in TGD framework?

1. The first thing to notice is that classical TGD predicts complex Noether charges since for instance Kähler coupling strength has imaginary part. This would suggest that the momenta of incoming particles could be complex. Could complex value of  $P(M^4) \equiv P$  implying

$$P^2 = Re(P)^2 - Im(P)^2 + i2Re(P) \cdot Im(P) = 0$$

save the situation? The condition requires that  $Re(P)$  and  $Im(P)$  are light-like and parallel so that one would obtain only light-like four-momenta as total  $M^4$  momenta.

2. However, in TGD light-likeness holds true in 8-D sense for single particle states: this led to the proposed generalization of twistor approach allowing particles to be massive in 4-D sense.  $M^8 - H$  duality allows to speak about light-like  $M^8$  momenta satisfying quaternionicity condition. The wave functions in  $CP_2$  degrees of freedom emerge from momentum wave functions in  $M^8$  degrees of freedom respecting quaternionicity. The condition  $P^2(M^8) = 0$  implies that  $Re[P(M^8)]$  and  $Im[P(M^8)]$  are light-like and parallel.  $Im[P(M^8)]$  can be arbitrarily small. One has also  $Re[P(M^4)]^2 = Re[P(E^4)]^2$  and  $Im[P(M^4)]^2 = Im[P(E^4)]^2$ .
3. Could one pose the condition  $P^2(M^8) = 0$  also on *many-particle states* or only to the many-particle states appearing as complex massless poles in the BCFW conditions? Kind of strong form of conformal invariance would be in question: not only single-particle states but also many-particle states would be massless in 8-D sense. Now  $s = Re[P(M^4)]^2 = Re[P(E^4)]^2$  could have a continuum of values. The discontinuity along  $s$ -axis required by unitarity would emerge from the discontinuity due to the pole at  $P^2(M^8) = 0$ ! Hence 8-dimensional light-likeness in strong sense would be absolutely essential for having vanishing loop corrections together with non-vanishing scattering rates!

Here one must be however extremely careful.

1. In BCFW approach the expression of residue integral as sum of poles in the variable  $z$  associated with the amplitude obtained by the deformation  $p_i \rightarrow p_i + zr_i$  of momenta ( $\sum r_i = 0$ ,  $r_i \cdot r_j = 0$ ) leads to a decomposition of the tree scattering amplitude to a sum of products of amplitudes in resonance channels with complex momenta at poles. The products involve  $1/P^2$  factor giving pole and the analog of cut in unitary condition. Proof of tree level unitarity is achieved by using complexified momenta as a mere formal trick and complex momenta are an auxiliary notion. The complex massless poles are associated with groups  $I$  of particles whereas the momenta of particles inside  $I$  are complex and non-light-like.
2. Could BCFW deformation give a description of massless bound states massless particles so that the complexification of the momenta would describe the effect of bound state formation on the single particle states by making them non-light-like? This makes sense if one assumes that all 8-momenta - also external - are complex. The classical charges are indeed complex already classically since Kähler coupling strength is complex [L2]. A possible interpretation for the imaginary part is in terms of decay width characterizing the life-time of the particle and defining a length of four-vector.
3. The basic question in the construction of scattering amplitudes is what happens inside CD for the external particles with light-like momenta. The BCFW deformation leading to factorization suggests an answer to the question. The factorized channel pair corresponds to two CDs inside which analogs of  $M$  and  $N - M$  particle bound states of external massless particles would be formed by the deformation  $p_i \rightarrow p_i + zr_i$  making particle momenta non-light-like. The allowed values of  $z$  would correspond to the physical poles. The factorization of BCFW scattering amplitude would correspond to a decomposition to products of bound state amplitudes for pairs of CDs. The analogs of bound states for zero energy states would be in question. BCFW factorization could be continued down to the lowest level below which no factorization is possible.
4. One can of course worry about the non-uniqueness of the BCFW deformation. For instance, the light-like momenta  $r_i$  must be parallel ( $r_i = \lambda_i r$ ) but the direction of  $r$  is free. Also the

choice of  $\lambda_i$  is free to a high extent. BCFW expression for the amplitude as a residue integral over  $z$  is however unique. What could this non-uniqueness mean?

Suppose one accepts the number theoretic vision that scattering amplitudes are representations for sequences of algebraic manipulations. These representations are bound to be highly non-unique since very many sequences can connect the same initial and final expressions. The space-time surface associated with given representation of the scattering amplitude is not unique since each computation corresponds to different space-time surface. There however exists a representation with maximal simplicity.

Could these two kinds of non-uniqueness relate?

It is indeed easy to see that many-particle states with light-like single particle momenta cannot have light-like momenta unless the single-particle momenta are parallel so that in non-parallel case one must give up light-likeness condition also in complex sense.

1. The condition of light-likeness in complex sense allows the vanishing of real and imaginary mass squared for individual particles

$$Im(p_i) = \lambda_i Re(p_i) \quad , \quad (Re(p_i))^2 = (Im(p_i))^2 = 0 \quad . \quad (3.3)$$

Real and imaginary parts are parallel and light-like in 8-D sense. All  $\lambda_i$  have same sign and  $p_i$  has positive or negative time component depending on whether positive or negative energy part of zero energy state is in question.

2. The remaining two conditions come from the vanishing of the real and imaginary parts of the total mass squared:

$$\sum_{i \neq j} Re(p_i) \cdot Re(p_j) - Im(p_i) \cdot Im(p_j) = 0 \quad , \quad \sum_{i \neq j} Re(p_i) \cdot Im(p_j) = 0 \quad . \quad (3.4)$$

By using proportionality of  $Im(p_i)$  and  $Re(p_i)$  one can express the conditions in terms of the real momenta

$$\sum_{i \neq j} (1 - \lambda_i \lambda_j) Re(p_i) \cdot Re(p_j) = 0 \quad , \quad \sum_{i \neq j} \lambda_j Re(p_i) \cdot Re(p_j) = 0 \quad . \quad (3.5)$$

For positive/negative energy part of zero energy state the sign of time component of momentum is fixed and therefore  $\lambda_i$  have fixed sign. Suppose that  $\lambda_i$  have fixed sign. Since the inner products  $p_i \cdot p_j$  of time-like vectors with fixed sign of time component are all positive or negative the second term can vanish only if one has  $p_i \cdot p_j = 0$ . If the sign of  $\lambda_i$  can vary, one can satisfy the condition linear in  $\lambda_i$  but not the first condition as is easy to see in 2-particle case.

3. States with light-like parallel 8-momenta are allowed and one can ask whether this kind of states might be realized inside magnetic flux tubes identified as carriers of dark matter in TGD sense. The parallel light-like momenta in 8-D sense would give rise to a state analogous to super-conductivity. Could this be true also for quarks inside hadrons assumed to move in parallel in QCD based model. This also brings in mind the earlier intuitive proposal that the momenta of fermions and antifermions associated with partonic 2-surfaces must be parallel so that the propagators for the states containing altogether  $n$  fermions and antifermions would behave like  $1/(p^2)^{n/2}$  and would not correspond to ordinary particles.

These arguments are formulated in  $M^8$  picture. What could this mean in  $M^4 \times CP_2$  picture?

1. The intuitive expectation is that  $Re[P(E^4)]^2$  corresponds to the eigenvalue  $\Lambda$  of  $CP_2$  d'Alembertian so that the higher the momentum, the larger the value of  $\Lambda$ .  $CP_2$  d'Alembertian would be essentially the  $M^4$  mass squared of the state. This would allow vanishing color quantum numbers  $Y$  and  $I_3$  but force symmetry breaking  $SU(3) \rightarrow SU(2) \times U(1)$ . This picture is not quite accurate: also the vibrational degrees of freedom contribute to the mass squared what might be called stringy contribution.



2. Could the geometry of  $CP_2$  induce this symmetry breaking? For instance, Kähler gauge potential depends on the  $U(2)$  invariant “radial” coordinate of  $CP_2$  and is invariant only under  $U(2)$  rotations and changes by gauge transformation in other color rotations. Could one assign the symmetry breaking to the choice of color quantization axes boiling down at the classical level to the fixing of  $CP_2$  Kähler function would?

One would have color confinement in weak sense: in QCD picture physical states correspond to color singlet representations. This is certainly very strong statement in a sharp conflict with the standard view about color confinement. It would make sense in TGD framework, where color as a spin like quantum number is replaced with angular momentum like quantum number. One could say that macroscopic systems perform macroscopic color rotation. The model for the honeybee dance [L9] conforms with this view and actually led to the proposal for a modification of cosmic string type extremals  $X^4 = X^2 \times Y^2 \subset M^4 \times CP_2$  by putting  $Y^2$  in 2-D rigid body color rotation along both time axis and spatial axis of the string world sheet  $X^2$ .

3. This picture raises again the old question about the relationship of color and electroweak quantum numbers in TGD framework. Could one regard electroweak quantum numbers as a spin related to color group  $SU(3)$  just as one can relate ordinary spin with Lorentz transformations? Color quantum numbers of say quarks would be analogous to orbital angular momentum. The realization of the action of the electroweak  $U(2)_{ew}$  on  $CP_2$  spinors indeed involves also geometric color rotation affecting the gauge potentials in the general case and  $U(2)_{ew}$  can be identified as holonomy group of  $CP_2$  spinor connection and subgroup of  $SU(3)$ . One could also see electroweak symmetry breaking as a further symmetry breaking  $U(2) \rightarrow U(1) \times U(1)$  assignable with the flag manifold  $SU(3)/U(1) \times U(1)$  parameterizing different choices of color quantization axes and having interpretation as  $CP_2$  twistor space.

**Remark:** Number theoretic vision means that the quaternionic  $M^8$ -momenta are discrete with components having values in the extension of rationals.  $P^2(M^4)$  becomes discrete if one poses  $P^2(M^8) = 0$  condition for all states. The values of discontinuity of  $Im(T)$  correspond now to a discrete sequence of poles along  $s$ -axis approximating cut. At the continuum limit this discrete sequence of poles becomes cut. Continuum limit would correspond to a finite measurement resolution in which one cannot distinguish the poles from each other.

### 3.3 Grassmannian approach and TGD

Grassmannian approach has provided besides technical progress deeper views about twistorialization and also led to the understanding of the Yangian symmetry.

#### 3.3.1 Grassmannian twistorialization - or what I understand about it

The twistorialization of the scattering amplitudes works for planar amplitudes in massless theories and involves the following ingredients.

1. All scattering amplitudes are expressible in terms of on-mass-shell scattering amplitudes with massless on-mass-shell particles in complex sense.
2. The scattering amplitude is sum over contributions with varying number of loops. BCFW recursion relation allows to construct scattering amplitudes from their singularities using 3-particle amplitudes as building brick amplitudes. There are two types of singularities.

For the first type of singularity one has on-shell internal line and one obtains a sum over all possible decompositions of the scattering amplitude to a product of on-mass-shell scattering amplitudes multiplied by delta function for momentum squared of the internal line. Second type of singularity corresponds to the so called forward limit and is obtained from  $(n+2, k)$  amplitude by contracting two added adjacent particles to form a loop so that their momenta are opposite and integrating over the momentum.

3. The singular term is algebraically analogous to an exterior derivative of the scattering amplitude and can be integrated explicitly: the integration adds BCFW bridge to the both

terms such that the forward limit loop in the second term is under the bridge. The outcome is BCFW formula for  $l$ -loop amplitude with  $n$  external particles with  $k$  negative helicities consisting of these two terms.

Twistor Grassmannian approach expresses the on mass shell scattering amplitudes appearing as building bricks as residue integrals over Grassmannian  $Gr(n, k)$ , where  $n$  is the number of particles and  $k$  is the the number of negative helicities. The Grassmannian approach is described in a concise form in the slides by Jaroslav Trnka [B5] (see <http://tinyurl.com/pqjzffj>).

1. The construction of the on-mass-shell scattering amplitudes appearing in BCFW formula as residue integrals in Grassmannians follows by expressing the momentum conserving delta functions in twistor description in terms of auxiliary variables serving as coordinates of Grassmannian  $G(n, k, C)$  for the on mass shell tree amplitude with  $n$  external particles having  $k$  negative helicities. Grassmannian has dimension  $d = (n - k)k$  and can be identified as the space of  $k$ -planes - or equivalently  $n - k$ -planes in  $C^N$ . Grassmannian has a representation as homogenous space  $G(n, k, C) = U(n)/U(n - k) \times U(k)$  having  $SU(n)$  as the group of isometries. For  $k = 1$  one obtains projective space which is also symmetric space (allowing reflection along geodesic lines as isometries).
2. Grassmannians emerge as an auxiliary construct, and the multiple residue integral over Grassmannian gives sum of residues so that the introduction of Grassmannians might look like un-necessary complication. The selection of points of Grassmannian for given external quantum numbers by residue integral given at the same time the value of the amplitude might however have some deeper meaning.

The construction involves standard mathematics, which is however new for physicists. For instance, notions such as Plücker coordinates, Schubert cells and cell decomposition appear. One can relate to each other various widely different looking expressions for the amplitudes as being associated with different cell decompositions of Grassmannian. The singularities of the integrand of the scattering amplitude defined as a multiple residue integral over  $G(k, n)$  define a hierarchy of Schubert cells.

3. The so called positive Grassmannian [B4] defines a subset of singularities appearing in the scattering amplitudes of  $\mathcal{N} = 4$  SUSY. The points of positive Grassmannian  $Gr_+(k, n)$  are representable as  $k \times n$  matrices with positive  $k \times k$  determinants. The singularities correspond to the boundaries of  $Gr_+(k, n)$  with some  $k \times k$  determinants vanishing. For tree diagrams the singularities correspond to poles appearing in the factorized term of the BCFW decomposition of the scattering amplitude. The positivity conditions hold true also for the twistors representing external particles.
4. Positivity conditions guarantee the convexity of the integration region determined by the  $C$ -matrix as point of  $Gr_+(k, n)$  appearing in the conditions dictating the integration region.

To better understand the meaning of positivity one can first consider triangle call it  $T$  - as a representation of positive Grassmannian  $Gr_+(1, 3) = P_+^2$ . Any interior points of  $T$  can be regarded as center of mass for suitable positive masses at the vertices of the triangle. These conditions generalizes to the case of general polygons, which must be convex. If the number of vertices of the polygon is larger than 3, convexity is not automatically satisfied, and requires additional conditions.

This description generalizes to Grassmannians  $Gr_+(k, n)$ . Masses define the analog of  $C$ -matrix as element of  $Gr_+(k, n)$  appearing in the twistor approach and the vertices of the triangle are analogous to the twistors associated with external particles combining to form a point of  $Gr(4, n)$ . Positivity condition is generalized to the condition that  $k \times k$  minors of the  $k \times n$  matrix are positive.

5. Also the twistors associated with the external particles must satisfy analogs of the positivity conditions. This involves the replacement of  $Gr(4, n)$  associated with twistors of the external particles with  $Gr_+(k + 4, n)$ . The additional  $k$  components of the twistors are Grassman numbers and determined by the superparts of the twistors (see the slides of Trnka at <http://tinyurl.com/pqjzffj>. I must admit that I did not understand this.

6. Residue integral can be defined in terms of what is called canonical form  $\Omega$  - analog of volume form - having logarithmic singularities at the boundaries of the  $Gr_+(k, n)$ . Hence one can perform a reduction of the residue integral to a sum of integrals over  $G(k, k+4)$  instead of  $G(k, n)$  (actually not so surprising since the residue integrals give as outcome the residues at discrete points!).

This leads to a reduction of the residue integral over  $Gr_+(k, n)$  to a sum of lower dimensional residue integrals over triangulation defined by  $Gr_+(k, k+4)$  represented as surfaces of  $Gr_+(k, n)$  glued together along sides. The geometric analog would be decomposition of polygon to a union of triangles.

This simplifies the situation dramatically [B6, B5, B4] and leads to the notion of amplituhedron [B2, B1]. What is so remarkable, is the simplicity of the expressions for all-loop amplitudes and the fact that positivity implies locality and unitarity for  $\mathcal{N} = 4$  SUSY.

7. It should be possible to construct  $\Omega$  explicitly having the desired singularities which would be in TGD framework poles with  $P^2(M^8) = P^2(M^4 \times CP_2) = 0$  if the proposed realization of unitarity makes sense? Could one just assume that  $\Omega$  vanishes for that part of the boundary of  $Gr_+(k, n)$ , which gives loop singularities? Could these points  $Gr_+(k, n)$  be transcendental and excluded for this reason?

If loop corrections are vanishing as ZEO strongly suggests, only tree amplitudes are needed. Therefore it is appropriate to summarize what I have managed to understand about the construction of the tree amplitudes with general value of  $k$  in the amplituhedron approach.

1. The notion of amplituhedron relies on the mapping of  $G(k, n)$  to  $G_+(k, k+m)$   $n \geq k+m$ . Actually a map from  $G(k, n) \times G(k+4, n) \rightarrow G_+(k, k+m)$  is in question.  $m = 4$  identifiable as the apparent dimension of twistor space without projective identification giving the actual dimension  $d = 3$ .  $n$  is the number of external particles and  $k$  the number of negative helicities. The value of  $m$  is  $m = 4$  and follows from the conditions that amplitudes come out correctly. The constraint  $Y = C \cdot Z$ , where  $Y$  corresponds to point of  $G_+(k, k+4)$  and  $Z$  to the point of  $G(k+4, n)$  performs this mapping, which is clearly many-to one. One can decompose integral over  $G_+(k, n)$  to integrals over positive regions  $G_+(k, k+4)$  intersecting only along their common boundary portions. The decomposition of a convex polygon in plane to triangles represent the basic example of this kind of decomposition. Obviously there are several decompositions of this kind.
2. Each decomposition defines a sum of contributions to the scattering amplitude involving integration of a projectively invariant volume form over the positive region in question. The form has a logarithmic singularity at the boundaries of the integration region but spurious singularities cancel so that only the contribution of the genuine boundary of  $G_+(k, k+4)$  remains. There are additional delta function constraints fixing the integral completely in real case.
3. In complex case one has residue integral. The proposed generalization to the complex case is by analytic continuation. TGD inspired proposal is that the positivity condition in the real case is generalized to the condition that the positive coordinates are replaced by complex coordinates of hyperbolic space representable as upper half plane or equivalently as the unit disk obtained from upper half plane by exponential mapping  $w = \exp(iz)$ . The measure  $d\alpha/\alpha$  would correspond to  $dz = dw/w$ . If taken over boundary circle labelled by discrete phase factors  $\exp(i\phi)$  given by roots of unity the integral would be numerically a discrete Riemann sum making no sense p-adically but residue theorem could allow to avoid the discretization and to define the p-adic variant of the integral by analytic continuation. These conditions would be completely general conditions on various projectively invariant moduli involved.
4. One must extend the bosonic twistors  $Z_a$  of external particles by adding  $k$  coordinates. This extension looks very difficult to understand intuitively. Somewhat surprisingly, these coordinates are anti-commutative super-coordinates expressible as linear combinations of fermionic parts of super-twistor using coefficients, which are also Grassmann numbers. Integrating over these one ends up with the standard expression of the amplitude using canonical integration

measure for the regions in the decomposition of amplituhedron. An interesting question is whether the addition of  $k$ -dimensional anti-commutative parts to  $Z_a$  expressible in terms of super-coordinates is only a trick or whether it could have some physical interpretation.

### 3.3.2 Grassmannians as reduced WCWs?

Grassmannians appear as auxiliary spaces in twistor approach. Could Grassmannians and the procedure assigning to external momenta and helicities discrete set of points of Grassmannian and scattering amplitude have some concrete interpretation in TGD framework?

1. The points of cognitive representation define WCW coordinates for space-time surface. For a fixed number of points in cognitive representation WCW is effectively replaced with a finite-dimensional reduced WCW. These points would naturally correspond to the points defining ends of fermionic lines at partonic 2-surfaces. WCW has Kähler metric with Euclidian signature. This could be true also for its reduction.
2. The experience with twistorialization suggests that these spaces could be simply Grassmannians  $Gr(n, r, C)$  consisting of  $r$ -dimensional complex planes of  $n$ -dimensional complex space representable as coset spaces  $U(n)/U(n-r) \times U(r)$  appearing as auxiliary spaces in the construction of twistor amplitudes.

Note that the correlation between quantum states and geometry would be present since  $n$  corresponds to the number of external particles and  $r$  to those with negative helicity in ordinary twistor Grassmann approach. In TGD framework discretized variants of these spaces corresponding to the extension of rationals used would appear. Yangian symmetries could correspond to general coordinate transformations for the reduced WCW acting as gauge symmetry. These transformations act as diffeomorphisms for so called positive Grassmannians also in the standard twistorialization. If the reduced WCWs indeed correspond to twistor Grassmannians, one would have a completely unexpected connection with supersymmetric QFTs.

3. The reduction of WCW to a finite dimensional Kähler manifold suggests that also WCW spinors become ordinary spinors for Kähler manifold so that gamma matrices form a finite-D fermionic oscillator operator algebra. WCW has maximal symmetries and it would not be surprising if also the finite-D Kähler manifold would possess maximal symmetries. Note that WCW gamma matrices together with isometry generators of WCW give rise to a super-symplectic algebra involving a generalization of 2-D conformal invariance replacing 2-D surfaces with light-like 3-surfaces.
4. The interpretation of supersymmetry would be different from the standard one. Kähler structure implies that  $\mathcal{N}$  is even and Majorana spinors are absent and both baryon and lepton number can be conserved separately. The ordinary fermionic oscillator algebra is a Clifford algebra and could be interpreted in terms of a broken supersymmetry.

Also more general flag manifolds than Grassmannians can be considered. If these spaces are homogenous spaces they have maximal isometries. They should have also Kähler structure. Compactness looks also a highly desirable property. The gauge conditions for the subalgebra of super-symplectic algebra state that the sub-algebra and its commutator with the entire algebra annihilate physical states and give rise to vanishing classical Noether charges. This would effectively reduce the super-symplectic algebra to a finite-D Lie group or Kac-Moody algebra of a finite-dimensional Lie group - perhaps belonging to the ADE hierarchy as the hierarchy of inclusions of HFFs as an alternative correlate for the realization of finite measurement resolution suggests. The flag manifolds associated with these Lie groups define more general homogenous spaces as candidates for the reduced WCWs.

### 3.3.3 Interpretation for Grassmannian residue integrations

The identification of Grassmannians (or possibly more general spaces) as reduced WCWs would give a genuine physical interpretation for the Grassmannian integrations as residue integrations

over reduced WCW. What looks mysterious and maybe even frustrating is that the outcome of the entire process is sum over discrete residues: what does this mean?

1. The residue integration is only over a surface of reduced WCW with dimension equal to one half of that of WCW. One has integrand, which depends on the external quantum numbers coded in terms of twistors and on coordinates of reduced WCW. The residue integration is analogous to summation over amplitude associated with space-time surfaces coded by different cognitive representations.
2. One can argue that a continuous residue integral over Grassmannian is not consistent with the number theoretic discretization. The outcome is however discrete set of space-time surfaces labelled by cognitive representations as points of Grassmannian. Of the points in question are in the extension and if this is equivalent with the corresponding property for the coordinates of Grassmannian, there should be no problems. The restriction of external momenta to the extension of rationals might guarantee this.
3. The full multiple residue integral leaves only pole contributions, which correspond to a discrete collection of space-time surfaces (at least the set of space-time surfaces obtained by the action of Galois group), that is discrete set of points of reduced WCW. It seems that the entire residue integration is just a manner to realize quantum classical correspondence by associating to the external quantum numbers space-time surfaces and corresponding cognitive representations - and of course, also the scattering amplitude.
4. One can also ask whether the positivity of Grassmannian might relate to the fact that p-adic numbers as ordinary integers are always non-negative (most of them infinite). The positivity might be necessary in order to have number theoretic universality. If the minors associated with the C-matrix serve as coordinates for  $Gr_+(k, n)$  they could be interpreted also as p-adic numbers. If they are allowed to be negative, one encounters problems since p-adic numbers are not well-ordered and one cannot say whether p-adic number is negative or positive.

### 3.3.4 Possible description of SUSY and its breaking in TGD framework

Although twistor description make sense also in the absence of supersymmetry, super-symmetry is an essential part of the elegance of the Grassmannian approach. For the ordinary SUSY one has gluons and their superpartners characterized in terms of super-twistors. In TGD one has two pictures [L5, K20].

1. At the level  $H$  fermions as fundamental particles are described in terms of second quantized induced spinor fields, whose oscillator operators can be used to build gamma matrices for WCW [K13, K15]. In TGD universe all known elementary particles would be composites of fundamental fermions represented as lines at the light-like orbits of partonic 2-surfaces (wormhole throats) and ordinary elementary particles involve a pair of wormhole contacts with throats containing these fermion lines. It is assumed that the fermions are at different points: this allows to avoid problems due to infinities.

In the proposed generalization of twistor approach  $2 \rightarrow 2$  fermion scattering in the classical fields at partonic 2-surface would define the basic  $2 \rightarrow 2$ -vertex replacing 3-vertices of twistorial SUSY. Essentially one has only two-vertices describing the redistribution of fermions at partonic 2-surface between orbits of the partonic 2-surfaces meeting at it. This is different from  $\mathcal{N} = 4$  SUSY [K19]. If one allows completely local multi-fermion states at the level of  $H$  one cannot avoid fermionic contact interactions.

The many-fermion states associated with partonic 2-surfaces would define the analogs of super-multiplets. One can wonder whether a SUSY type description could exist as a limit when the partonic 2-surface is approximated with single point so that also positions of fermions are approximated as single point. SUSY would be only approximate.

2. At the level of  $M^8$  I have proposed the use of polynomials  $P$  of super-octonion serving as analogs of super-gluon fields to construct scattering amplitudes [L5]. This allows geometric description of all particles using super-multiplets. Each monomial of theta parameters would

give rise to its own space-time surface by the condition that either  $IM(P)$  or  $RE(P)$  vanishes for the corresponding polynomial  $P$ . This condition would reduce the components of super-field to algebraic surfaces.

There is however an important difference from  $H$  picture. The members of super-multiplet defined by  $P$  correspond to the coefficients of monomials of theta parameters having interpretation as analogs of oscillator operators. Super-partners would be in this sense point-like objects unlike in  $H$  approach, where this can hold true only approximately.

Could  $H$ - and  $M^8$  pictures be equivalent and could one understand the breaking of SUSY in this framework?

1.  $M^8 - H$  correspondence as a map of associative space-time regions from  $M^8$  to minimal surfaces in  $H$  makes sense for the external particles and thus at boundaries of CDs. It assigns to a point of the partonic 2-surface  $X^2 \subset X^4 \subset M^8$  the quaternionic tangent space of  $X^4$  at it characterized by a point of  $CP_2$ .  $M^4$  point is mapped to itself. There is additional condition requiring that quaternionic tangent space contains fixed complex sub-space but this is not relevant now.
2. Could this map be one-to-many so that super-field component describing purely many-fermion state would be mapped to several points at the image of  $X^2$  in  $H$  describing multi-local many-fermion state? This is possible if the points in  $M^8$  are singular in the sense that the action of a normal subgroup  $H$  of Galois group  $Gal$  leaves the point invariant so that  $Gal$  reduces to  $Gal/H$ : symmetry breaking takes place.

The tangent spaces of the degenerate points are however different and are mapped to different points of  $CP_2$  in  $M^8 - H$  correspondence making sense at boundaries of CDs but not in their interiors. One would have several fermions with same  $M^4$  coordinates but different  $CP_2$  coordinates and the outcome would be many-fermion state. In the case of 2-fermion state the different values of  $CP_2$  coordinates would be associated with the opposite throats of a wormhole contact whose orbit defines light-like 3-surface. Could light-likeness inducing the reduction of the metric dimension of the tangent space from 4 to 3 somehow induce also this degeneration?

3. Could symmetry breaking as a degeneration of  $Gal$  action to that for  $Gal/H$  take place for the conditions defining the 4-surfaces associated with the higher components of super-octonion and induce the breaking of SUSY at the level of  $M^8$  manifesting as the non-locality of the fermion state at the level of  $H$ ? This degeneration would be a typical manifestation of quantum criticality: criticality in general means co-incidence of two roots.

### 3.4 Summary

Since the contribution means in well-defined sense a breakthrough in the understanding of TGD counterparts of scattering amplitudes, it is useful to summarize the basic results deduced above as a polished answer to a Facebook question.

There are two diagrammatics: Feynman diagrammatics and twistor diagrammatics.

1. Virtual state is an auxiliary mathematical notion related to Feynman diagrammatics coding for the perturbation theory. Virtual particles in Feynman diagrammatics are off-mass-shell.
2. In standard twistor diagrammatics one obtains counterparts of loop diagrams. Loops are replaced with diagrams in which particles in general have complex four-momenta, which however light-like: on-mass-shell in this sense. BCFW recursion formula provides a powerful tool to calculate the loop corrections recursively.
3. Grassmannian approach in which Grassmannians  $Gr(k, n)$  consisting of  $k$ -planes in  $n$ -D space are in a central role, gives additional insights to the calculation and hints about the possible interpretation.
4. There are two problems. The twistor counterparts of non-planar diagrams are not yet understood and physical particles are not massless in 4-D sense.

In TGD framework twistor approach generalizes.

1. Massless particles in 8-D sense can be massive in 4-D sense so that one can describe also massive particles. If loop diagrams are not present, also the problems produced by non-planarity disappear.
2. There are no loop diagrams- radiative corrections vanish. ZEO does not allow to define them and they would spoil the number theoretical vision, which allows only scattering amplitudes, which are rational functions of data about external particles. Coupling constant evolution - something very real - is now discrete and dictated to a high degree by number theoretical constraints.
3. This is nice but in conflict with unitarity if momenta are 4-D. But momenta are 8-D in  $M^8$  picture (and satisfy quaternionicity as an additional constraint) and the problem disappears! There is single pole at zero mass but in 8-D sense and *also many-particle states* have vanishing mass in 8-D sense: this gives all the cuts in 4-D mass squared for all many-particle state. For many-particle states not satisfying this condition scattering rates vanish: these states do not exist in any operational sense! This is certainly the most significant new discovery in the recent contribution.

BCFW recursion formula for the calculation of amplitudes trivializes and one obtains only tree diagrams. No recursion is needed. A finite number of steps are needed for the calculation and these steps are well-understood at least in 4-D case - even I might be able to calculate them in Grassmannian approach!

4. To calculate the amplitudes one must be able to explicitly formulate the twistorialization in 8-D case for amplitudes. I have made explicit proposals but have no clear understanding yet. In fact, BCFW makes sense also in higher dimensions unlike Grassmannian approach and it might be that the one can calculate the tree diagrams in TGD framework using 8-D BCFW at  $M^8$  level and then transform the results to  $M^4 \times CP_2$ .

What I said above does yet contain anything about Grassmannians.

1. The mysterious Grassmannians  $Gr(k, n)$  might have a beautiful interpretation in TGD: they could correspond at  $M^8$  level to reduced WCWs which is a highly natural notion at  $M^4 \times CP_2$  level obtained by fixing the numbers of external particles in diagrams and performing number theoretical discretization for the space-time surface in terms of cognitive representation consisting of a finite number of space-time points.

Besides Grassmannians also other flag manifolds - having Kähler structure and maximal symmetries and thus having structure of homogenous space  $G/H$  - can be considered and might be associated with the dynamical symmetries as remnants of super-symplectic isometries of WCW.

2. Grassmannian residue integration is somewhat frustrating procedure: it gives the amplitude as a sum of contributions from a finite number of residues. Why this work when outcome is given by something at finite number of points of Grassmannian?!

In  $M^8$  picture in TGD cognitive representations at space-time level as finite sets of points of space-time determining it completely as zero locus of real or imaginary part of octonionic polynomial would actually give WCW coordinates of the space-time surface in finite resolution.

The residue integrals in twistor diagrams would be the manner to realize quantum classical correspondence by associating a space-time surface to a given scattering amplitude by fixing the cognitive representation determining it. This would also give the scattering amplitude.

Cognitive representation would be highly unique: perhaps modulo the action of Galois group of extension of rationals. Symmetry breaking for Galois representation would give rise to supersymmetry breaking. The interpretation of supersymmetry would be however different: many-fermion states created by fermionic oscillator operators at partonic 2-surface give rise to a representation of supersymmetry in TGD sense.

## 4 New insights about quantum criticality for twistor lift inspired by analogy with ordinary criticality

Quantum criticality (QC) is one of the basic ideas of TGD. Zero energy ontology (ZEO) is second key notion and leads to a theory of consciousness as a formulation of quantum measurement theory making observer part of the quantum system in terms of notion of self identified as a generalized Zeno effect or analog for a sequence of weak measurements, and solving the basic paradox of standard quantum measurement theory, which one usually tries to avoid by introducing some “interpretation”.

ZEO allows to see quantum theory could be seen as “square root” of thermodynamics. It occurred to me that it would be interesting to apply this vision in the case of quantum criticality to perhaps gain additional insights about its meaning. We have a picture about criticality in the framework of thermodynamics: what would be the analogy in ZEO based interpretation of Quantum TGD? Could it help to understand more clearly the somewhat poorly understood views about the notion of self, which as a quantum physical counterpart of observer becomes in ZEO a key concept of fundamental physics?

The basic ingredients involved are discrete coupling constant evolution, zero energy ontology (ZEO) implying that quantum theory is analogous to “square root” of thermodynamics, self as generalized Zeno effect as counterpart of observer made part of the quantum physical system,  $M^8 \leftrightarrow M^4 \times CP_2$  duality, and quantum criticality. A further idea is that vacuum functional is analogous to a thermodynamical partition function as exponent of energy  $E = TS - PV$ .

The correspondence rules are simple. The mixture of phases with different 3-volumes per particle in a critical region of thermodynamical system is replaced with a superposition of space-time surfaces of different 4-volumes assignable to causal diamonds (CDs) with different sizes. Energy  $E$  is replaced with action  $S$  for preferred extremals defining Kähler function in the “world of classical worlds” (WCW).  $S$  is sum of Kähler action and 4-volume term, and these terms correspond to entropy and volume in the generalization  $E = TS - PV \rightarrow S$ .  $P$  resp.  $T$  corresponds to the inverse of Kähler coupling strength  $\alpha_K$  resp. cosmological constant  $\Lambda$ . Both have discrete spectrum of values determined by number theoretically determined discrete coupling constant evolution. Number theoretical constraints force the analog of micro-canonical ensemble so that  $S$  as the analog of  $E$  is constant for all 4-surfaces appearing in the quantum superposition. This implies quantization rules for Kähler action and volume, which are very strong since  $\alpha_K$  is complex.

This kind of quantum critical zero energy state is created in unitary evolution created in single step in the process defining self as a generalized Zeno effect. This unitary process implying time de-localization is followed by a weak measurement reducing the state to a fixed CD so that the clock time identified as the distance between its tips is well-defined. The condition that the action is same for all space-time surfaces in the superposition poses strong quantization conditions between the value of Kähler action (Kähler coupling strength is complex) and volume term proportional to cosmological constant. The outcome is that after sufficiently large number of steps no space-time surfaces satisfying the conditions can be found, and the first reduction to the opposite boundary of CD must occur - self dies. This is the classical counterpart for the fact that eventually all state function reduction leaving the members of state pairs at the passive boundary of CD invariant are made and the first reduction to the opposite boundary remains the only option.

The generation of magnetic flux tubes provides a manner to satisfy the constancy conditions for the action so that the existing phenomenology as well as TGD counterpart of cyclic cosmology as re-incarnations of cosmic self follows as a prediction. This picture allows to add details to the understanding of the twistor lift of TGD at classical level and allows an improved understanding of the p-adic length scale evolution of cosmological constant solving the standard problem caused by the huge value of  $\Lambda$ . The sign of  $\Lambda$  is predicted correctly.

This picture generalizes to the twistor lift of TGD and cosmology provides an interesting application. One ends up with a precise model for the p-adic coupling constant evolution of the cosmological constant  $\Lambda$  explaining the positive sign and smallness of  $\Lambda$  in long length scales as a cancellation effect for  $M^4$  and  $CP_2$  parts of the Kähler action for the sphere of twistor bundle in dimensional reduction, a prediction for the radius of the sphere of  $M^4$  twistor bundle as Compton length associated with Planck mass ( $2\pi$  times Planck length), and a prediction for the p-adic coupling constant evolution for  $\Lambda$  and coupling strength of  $M^4$  part of Kähler action giving also



insights to the CP breaking and matter antimatter asymmetry. The observed two values of  $\Lambda$  could correspond to two different p-adic length scales differing by a factor of  $\sqrt{2}$ .

## 4.1 Some background

Some TGD background is needed to understand the ideas proposed in the sequel.

### 4.1.1 Discrete coupling constant evolution

The most obvious implication is discrete coupling constant evolution in which the set of values for coupling constants is discrete and analogous to the set of the critical values of temperature [L12] (see <http://tinyurl.com/y9hlt3rp>). Zeros of Riemann Zeta or its slight modification suggest themselves as the spectrum for the Kähler coupling strength. This discrete coupling constant evolution requires that loop corrections vanish. This vision is realized concretely in the generalization of the twistorial approach to the construction of scattering amplitudes [L12].

Non-manifest unitarity is the basic problem of the twistor Grassmann approach. A generalization of the BCFW formula without the loop corrections gives scattering amplitudes satisfying unitary constraints. The needed cuts are replaced by sequences of massless poles in 8-D sense and cuts approximate these sequences (consider electrostatic analogy in which line charge approximates a discrete sequences of poles). The replacement cuts with sequences of poles is forced by the number theoretic discretization of momenta so that they belong to an extension of rationals defining the adèle [L6] (see <http://tinyurl.com/ycbhse5c>).

Non-planar loop diagrams are a chronic problem of twistor approach since there is no general rule loop integrations allowing to combine them neatly. Also this problem disappears now.

$M^8 - H$  duality plays key role in the twistorial approach [L5] (see <http://tinyurl.com/yd43o2n2>). In the ordinary twistor approach all momenta are light-like so that it does not apply to massive particles. TGD solves this problem: at  $M^8$  level one has quaternionic light-like 8-D momenta, which correspond to massive 4-D momenta in  $M^8$  picture. In  $H = M^4 \times CP_2$  picture ground states of super-conformal representations are constructed in terms of spinor harmonics of in  $M^4 \times CP_2$ , which are products plane-waves characterized by massive 4-momenta and color wave functions associated with massless Dirac equation in  $H$ . Also the analog of Dirac equation for the induced spinor fields at space-time surface is massless [K13] (see <http://tinyurl.com/yc2po5gf>).

### 4.1.2 ZEO and self as generalized Zeno effect

ZEO allows to see self as generalized Zeno effect [L8](see <http://tinyurl.com/ycxm2tpd>).

1. Generalized Zeno effect can be regarded as a sequence of “small” state function reductions analogous to weak measurements performed at active boundary of causal diamond (CD). In usual Zeno effect the state is unaffected under repeated measurements: now the same is true at passive boundary of CD whereas the members of state pairs at the active boundary change. The unitary evolutions followed by these evolutions leave thus passive boundary and states at it invariant whereas active boundary shifts farther away from the passive boundary and the members of state pairs at it are affected. This gives rise to the experienced flow of time.

The change of states is characterized unitary S-matrix. Each unitary evolution involves delocalization in the space of CDs so that one has quantum superposition of CDs with sizes not smaller than the CD to which the state was localized at previous reduction. This gives rise to a steady increase of clock time defined as the distance between the tips of CD. Self dies and reincarnates as a self with opposite direction of clock time when the first unitary evolution at the passive boundary followed by a weak measurement at it takes place. Self dies when all observables leaving the states at passive boundary invariant are measured. There are no choices to be made anymore.

2. Quantum TGD as “square root ” of thermodynamics means that the partition function of thermodynamics is replaced by its “square root” defined by the vacuum functional identified as exponent of Kähler function of “world of classical worlds” (WCW). Kähler function is analogous to energy  $E = TS - PV$  in thermodynamics with  $T$  replaced with the inverse

of complex Kähler coupling strength and  $P$  with cosmological constant, which have discrete spectrum of values.

One has the analog of micro-canonical ensemble for which only states with given energy are possible. Now the action (Kähler function) is same for the space-time surfaces assignable to the zero energy states involved. This condition allows to get rid of the exponentials defining the vacuum functional otherwise appearing in the scattering amplitudes. This condition is strongly suggested by number theoretic universality for which these exponentials are extremely troublesome since both the exponent and exponential should belong to the extension of rationals used.

This implies a huge simplification in the construction of the amplitudes [L5] (see <http://tinyurl.com/yd43o2n2>) because finite measurement resolution effectively replaces space-time surfaces with their cognitive representation defined by a discrete set of space-time points with imbedding space coordinates in the extension of rationals defining the adèle. This representation codes for the space-time surface if it corresponds to zero locus of real or imaginary part (in quaternionic sense) of an octonionic polynomial with real coefficients. WCW coordinates are given by the cognitive representation and are discrete. One is led to enumerative algebraic geometry.

#### 4.1.3 $M^8 - H$ duality

$M^8 - H$  duality [L5] (see <http://tinyurl.com/yd43o2n2>) states that the purely algebraic dynamics determined by the vanishing of real or imaginary part for octonionic polynomial is dual to the dynamics dictated by partial differential equations for an action principle.

1. The  $M^8$  counterparts of space-time surfaces are obtained as  $M^8$  projections of algebraic surfaces in the complexification  $M_c^8$  by imaginary unit commuting with octonionic units. One can decompose these surfaces to regions with associative (quaternionic) tangent space or normal space and they are analogous to external particles of a twistor diagram entering CD and to interaction regions in which associativity does not hold true and which correspond to interiors of CD.
2. At the level of  $H$  external particles correspond to minimal surfaces, which are also extremals of Kähler action and in accordance with the number theoretical universality and quantum criticality do not depend on the coupling parameters at all. They are obtained by a map taking the 4-surfaces in  $M^8$  to those in  $H$ . These conditions should be equivalent with the condition that the 6-D surfaces  $X^6$  in 12-D twistor space of  $H$  define twistor bundles of space-time surfaces  $X^4$ .
3. The space-time regions in the interiors of CDs are not minimal surfaces so that Kähler action and volume term couple dynamically and coupling parameters characterize the extremals. The analog is motion of point like particle in the Maxwell field defined by induced Kähler form: this is generalize to the motion of 3-D object with purely internal Kähler field and that associated with wormhole contacts and mediating interaction with larger and smaller space-time sheets.

In these regions the map mediating  $M^8 - H$  duality does not exist since one cannot label the tangent spaces of space-time surface by points of  $CP_2$ . The non-existence of this map is due to the failure of either associativity of tangent space or normal space at  $M^8$  level. The initial values at boundaries of CD for the incoming preferred extremals however allows to fix the time evolution in the interior of CD. This is essentially due to the infinite number of gauge conditions for the super-symplectic algebra.

#### 4.1.4 Quantum criticality

Quantum criticality is a further key notion of TGD and was originally motivated by the idea that Kähler coupling strength must be unique in order that the theory is unique.

1. The first implication of quantum criticality is quantization of various coupling strengths as analogs of critical temperature and of other critical parameters such as pressure. This quantization is required also by number theoretical universality in the adelic approach: coupling constant parameters must belong to the extension of rationals used.
2. Second implication of quantum criticality is a huge generalization of conformal symmetries to their 4-D analogs. The key observation is that 3-D light-like surfaces allow a generalization of conformal invariance to get the Kac-Moody algebra associated with the isometries of  $H$  (at least) as symmetries. In the case of boundary of CD this leads to what I call supersymplectic invariance: the symplectic transformations of the two components of  $\delta CD \times CP_2$  act as isometries of WCW. This algebra allows a fractal hierarchy of sub-algebras isomorphic to the algebra itself and gauge conditions state that this kind of sub-algebra and its commutator with the entire algebra annihilate physical states and classical Noether charges for them vanish [L12] (see <http://tinyurl.com/y9h1t3rp>). By quantum classical correspondence (QCC) the eigenvalues of quantum charges are equal to the classical Noether charges in Cartan algebra of supersymplectic algebra.
3. The third implication is the understanding of preferred extremals in  $H = M^4 \times CP_2$  and their counterparts at the level of  $M^8$ . Associativity condition at the level of  $M^8$  satisfied by the spacetime surfaces representing external particles arriving into CD corresponds to quantum criticality posing conditions on the coefficients of octonionic polynomials. The space-time regions inside CD the space-time surfaces do not satisfy associativity conditions and are not critical.
4. TGD as “square root” of thermodynamics idea suggests a fourth application of quantum criticality. This analogy might allow a better understanding of self as Zeno effect. This application will be studied in the sequel.

## 4.2 Analogy of the vacuum functional with thermodynamical partition function

Consider first the thermodynamical view about criticality. I have discussed criticality from slightly different perspective in [L10] (see <http://tinyurl.com/ydhknc2c>).

1. Thermodynamical states in critical region, where phases with different densities - say liquid and gas - are present serves as a basic example. This situation is actually a problem of the approach relying on partition function as van der Waals equation predicting 3 different densities for the density of molecules as function of pressure and temperature. Cusp catastrophe gives a view about situation: number density  $n$  is behavior variable and  $P$  and  $T$  are the control variables.
2. The experimental fact is that the density is constant as function of volume  $V$  for fixed temperature  $T$  whereas van der Waals predicts dependence on  $V$ . The phase corresponding to the middle sheet of the cusp is not at all present and the portions of liquid and gas phases vary. Maxwell’s rules (area rule and lever rule) allow to solve the problem plaguing actually all approaches based on partition function. Lever rule assumes that there are actually two kinds of “elements” present. Molecules are the first element but what the second element could be? TGD identification is as magnetic tubes [L10].
3. In the more general case in which the catastrophe is more general than cusp and has more sheets, two or more phases with different volumes are present and their volumes and possibly other behavior variables analogous to volume vary at criticality.
4. If one applies criticality in stronger sense by requiring that the function which has extremum as function of  $n$  at the surface represented by cusp catastrophe has same value at different sheets of the cusp, only the boundary line of the cusp having V-shaped projection in  $(p, T)$ -plane remains.

### 4.2.1 Generalization of thermodynamical criticality to TGD context

The generalization of this picture to TGD framework replaces the mixture of thermodynamical phases with different volumes with quantum superposition of space-time surfaces with different 4-volumes assignable to CDs with different quantized sizes (by number theoretical constraints).

1. Vacuum functional, which is exponent of Kähler function of WCW expressible as Kähler action for its preferred extremal, can be regarded as a complex “square root” of thermodynamical partition function  $Z$  meaning that its real valued modulus squared is analogous to partition function [K11, K19, K18, K20].

Action  $S$ , whose value for preferred extremal defines Kähler function of WCW serves as the analog of energy assumed to have expression  $E = PV - TS$ , which is not generally true but implied by the condition that  $E$  is homogenous as function of conjugate variable pairs  $P, V$  and  $T, S$ . The analogs of  $P$  and  $T$  correspond to coupling constant parameters. Pressure  $p$  is replaced with the coefficient of volume term in action - essentially cosmological constant.  $T$  is replaced with the coefficient  $1/\alpha_K$  of Kähler action representing entropy (or negentropy depending on situation).

**Remark:** Note that  $T$  corresponds now to  $1/\alpha_K$  rather than  $\alpha_K$  analogous to temperature when Kähler action  $S_K$  is regarded as analog of energy  $E$  rather than entropy  $S$ .

2. Quantum criticality in the sense of ZEO is the counterpart for the criticality in thermodynamics. The mixture of thermodynamical phases with different 3-volumes is replaced with quantum superposition of zero energy states with 4-surface having same action  $S$  but different 4-volumes assignable to different CDs. Critical system consists of several phases with same values of coupling parameters  $\alpha_K$  and  $\Lambda$  but different 4-volume.

There is also a number theoretic constraint identifiable as the counterpart of the constant energy condition defining micro-canonical ensemble. The exponent of action  $S$  must cancel from the scattering amplitudes to avoid serious existence problems in the p-adic sectors of adèle associated with given extension of rationals. Criticality means thus that  $exp(S)$  has same value for all preferred extremals involved. Real parts are same for all of them and imaginary parts of the action exponential are fixed modulo multiple of  $2\pi$ . The analog in the case of van der Waals equation of state that the allowed states are associated with the boundary of the projection of the cusp catastrophe to  $(p, T)$  plane.

Critical quantum states are superpositions of space-time surfaces with different 4-volumes associated with CDs with quantized size scales (distance between tips) and are generated by unitary evolution. The value of time as size of CD (distance between its tips) is not well-defined in these states.

**Remark:** Quantum critical states are “timeless” as meditative practices would express it.

This kind of superposition is created by unitary evolution operator at each step in the sequence of unitary evolutions followed by a state function reduction measuring clock time as the distance between the tips of CD. Localization to single CD is the outcome and only superposition with same time-scale and same  $S$  but possibly different 4-volumes.

3. The condition that action is same is very strong and applies to both real and imaginary parts of action ( $\alpha_K$  is complex). The proposal [L2, L12] (see <http://tinyurl.com/yas6ofhv> and <http://tinyurl.com/y9h1t3rp>) is that the coupling constant evolution as p-adic length scale  $p \simeq 2^k$ ,  $k$  prime corresponds to zero of Riemann  $\zeta$  for  $1/\alpha_K$  or is proportional to it by rational multiplier  $q$ . For  $q = 1$   $Re(1/\alpha_K)$  analogous to the ordinary temperature would be equal to  $Re(s) = 1/2$  for the zeros at the critical line and imaginary parts would correspond to the imaginary parts  $Im(s)$  of the zeros. Constancy of the action  $S$  would boil down to the conditions

$$Re(S_K) + Re(S_{vol}) = constant \quad , \quad Im(S_K) + Im(S_{vol}) = constant \quad mod \quad 2\pi \quad . \quad (4.1)$$

Note that the condition for imaginary part is a typical quantization condition.

4-volume can have arbitrary large values but for  $S_K$  this is probably not the case - this already by the quantization conditions. Hence one expects that there is some maximal possible volume for preferred extremals and thus maximal distance between the tips of CDs involved.

When the zero energy state is a superposition of only space-time surfaces with this maximal volume, further unitary evolutions are not possible and the first state function reduction to the opposite boundary of CD happens (death of self and reincarnation with opposite direction of clock time). Self has finite lifetime! This would be the classical correlate for the situation in which no quantum measurements leaving invariant the members of state pairs at the passive boundary of CD are possible.

#### 4.2.2 The constancy of $Re(S)$

How the cancellation of real part of  $\Delta(Re(S_K)) + \Delta(Re(S_{vol}))$  could take place?

1. The physical picture is that the time evolution giving rise to self starts from flux tube dominated phase obtained in the first state function reduction to the opposite boundary of CD and that also asymptotically one obtains flux tube dominated phase again but the flux tubes are scaled up. This is the TGD view about quantum cosmology as a sequences of selves and of their time reversals [K10] [L3] (see <http://tinyurl.com/y7fmaapa>). This picture suggests that the generation of magnetic flux tubes allows to satisfy the  $\Delta Re(S_K) + \Delta Re(S_{vol}) = 0$  condition: in Minkowskian regions the change magnetic part of  $\Delta Re(S_K)$  tends to cancel  $\Delta Re(S_{vol})$  whereas the electric part is of the same sign. Therefore magnetic flux tubes are favored.

If the sign of the volume term is negative the exponential defining the vacuum functional decreases with volume. If the relative sign of  $S_K$  and  $S_{vol}$  is negative, the magnetic part of the action is positive. The generation of flux tubes generates positive magnetic action  $\Delta S_K$  helping to cancel the change  $\Delta S_{vol}$ .

The additional conditions coming from the imaginary parts are analogous to semiclassical quantization conditions.

2. The proposed picture can be realized by a proper choice of the relative signs of volume term and Kähler action term. The relative sign comes automatically correct for a positive value of cosmological constant  $\Lambda$ . For this choice the total action density is

$$L_{tot} = (L_K + \frac{\Lambda}{8\pi G})\sqrt{g_4} . \quad (4.2)$$

This choice gives positive vacuum energy density associated with the volume term.

3. The density of Kähler action associated with  $CP_2$  degrees of freedom is

$$L_{K,CP_2} = -\frac{1}{4g^2} J^{\mu\nu} J_{\mu\nu} . \quad (4.3)$$

The action is proportional to  $E^2 - B^2$  in Minkowskian regions and magnetic term has sign opposite to that of volume term so that these terms can compensate with the condition guaranteeing constant action. The overall sign of action in the exponent can be chosen so that the exponential vanishes for large volumes. This suggests that the volume term is negative in the vacuum functional (Kähler function as negative of the action for preferred extremal). Euclidian regions, where  $CP_2$  part of Kähler action is of form  $B^2 + E^2$  and tends to cancel the volume term.

4. There is also Kähler action in  $M^4$  degrees of freedom. In twistor lift dimensional reduction occurs for 6-D Kähler action and  $M^4$  part and  $CP_2$  part contribute to Kähler action. The  $S^2$  parts of these actions must give rise to a cosmological constant decreasing like the inverse

of p-adic length scale squared. This is achieved if the Kähler contributions have opposite signs so that  $M^4$  contribution has a non-standard sign. This is possible if  $M^4$  Kahler form is proportional to imaginary unit and  $M^4$  Kähler coupling strength contains additional scaling factor.

The induced Kähler form must be sum of the  $M^4$  parts and  $CP_2$  parts and also the action must be sum of  $M^4$  and  $CP_2$  parts. This is achieved if the charge matrices of these two Kähler forms are orthogonal (the trace of their product vanishes). Since  $CP_2$  part couples to both 1 and  $\Gamma_9$  giving rise to Kähler charges proportional to 1 for quarks and 3 for leptons having opposite chiralities, the corresponding charges would be proportional to 3 for quarks and -1 for leptons.

The imaginary unit multiplying  $M^4$  Kähler form disappears in action and field equations and one obtains

$$L_K = -\frac{1}{4g_K^2}(\epsilon^2 J^2(M^4) + J^2(CP_2)) \quad , \quad (4.4)$$

where  $\epsilon$  is purely imaginary so that one has  $\epsilon^2 < 0$ . Since the fields are induced, negative sign for  $M^4$  Kähler action is not expected to lead to difficulties if  $M^4$  term is small.

Some examples are in order.

1. For cosmic string extremals Kähler action is multiple of volume action. The condition that the two actions cancel would give a constraint between  $\Lambda$  and  $\alpha_K$ . Net string tension would be reduced from the value determined by  $CP_2$  scale to a rather small value. This need not occur generally but might be true for very short p-adic length scales, where  $\Lambda$  is large as required by the large value of string tension associated with Kähler action. For thickened cosmic strings (magnetic flux tubes) the value of string tension assignable to Kähler action is reduced and the condition can be satisfied for smaller values of  $\Lambda$ .
2. For  $CP_2$  type extremals assignable to wormhole contacts serving as basic building bricks of elementary particles the action would be finite for all size scales of CD. Both magnetic and electric contribution to the action are of same sign. For Euclidian regions with 4-D space-time projection with so strong electric field that it changes the signature of the induced metric the same is true.
3. One can ask whether blackhole interiors as Euclidian regions correspond to these Euclidian space-time sheets or to highly tangled magnetic flux tubes with length considerably longer than Schwarzschild radius for which cancellation also can occur (see <http://tinyurl.com/ydhknc2c>). Both pictures are consistent in many-sheeted space-time: magnetic flux tube tangle could topologically condense to a space-time sheet with Euclidian signature. Cancellation cannot last for ever so that also blackholes are unstable against big state function reduction changing the arrow of time. Blackhole evaporation might relate to this instability.

### 4.2.3 The constancy of $Im(S)$ modulo $2\pi$

If cosmological constant is real, the condition for the constancy of imaginary part of  $\Delta S$  modulo  $2\pi$  applies only to the case of  $S_K$  and implies that  $\Delta S_K$  is fixed modulo  $2\pi$  in the superposition of space-time surfaces. If zeros of  $\zeta$  [L2] (see <http://tinyurl.com/yas6ofhv>) or its modification  $Zeta$ ) [L12]) (see <http://tinyurl.com/y9hlt3rp>) give the spectrum of  $1/\alpha_K$  the value of  $\Delta S_{K,red} = \int Tr(J^2)dV$  is given as multiples of  $2\pi n/y$ , where  $y$  is imaginary part for a zero of zeta. The constancy of  $Re(S)$  implies that the 4-volume  $\Delta V$  is quantized as multiples of  $2\pi n/\Lambda$ . These conditions bring in mind semiclassical quantization of the action in multiples of  $\hbar$ .

It however turns out that twistor lift forces same phase for  $M^4$  and  $CP_2$  parts of the Kähler action so that the quantization condition for volume is lost. The reason is that  $1/\alpha_K(M^4)$  and  $1/\alpha_K(CP_2)$  are proportional to

$$\frac{1}{\alpha_{K,6}} = \frac{1}{\alpha_{K,4}R^2} , \quad (4.5)$$

where  $R^2$  has dimensions of length squared.

### 4.3 Is the proposed picture consistent with twistor lift of Kähler action?

Is it possible to realize the cancellation of real parts of  $\Delta S_{vol}$  and  $\Delta S_K$  (modulo  $2\pi$  for imaginary part) for the twistor lift of Kähler action? Does the sign of the cosmological constant  $\Lambda$  come out correctly (wrong sign of  $\Lambda$  is the probably fatal problem of M-theory)? Can one understand the p-adic evolution of the cosmological constant  $\Lambda$  implying that  $\Lambda$  becomes small in long p-adic length scales and thus solving the key problem related to  $\Lambda$ ?

#### 4.3.1 Dimensional reduction of the twistor lift

The condition that the induction of the product of twistor bundles of  $M^4$  and  $CP_2$  to the space-time surface gives the twistor bundle of the space-time surface is conjectured to determine the dynamics of the space-time surfaces. A generalization of 4-D Kähler action to 6-D Kähler action is proposed to give this dynamics, and to dimensionally reduce to a sum of Kähler actions associated with  $M^4$  and  $CP_2$  Kähler forms plus cosmological term.

1. Twistor bundles are sphere bundles. For the extremals of 6-D Kähler action dimensional reduction takes place since 6-D extremals must be twistor bundle of corresponding space-time surface. Therefore  $S^2$  degrees of freedom are frozen and become non-dynamical.

One could say that the spheres appearing as fibers of twistor bundles of  $M^4$  and  $CP_2$  are identified in the imbedding map. The simplest correspondence between  $S^2(M^4)$  and  $S^2(CP_2)$  identifies  $(\theta_1, \phi_1)$  for  $S^2(M^4)$  with  $(\theta_2, \phi_2)$  for  $S^2(CP_2)$ . This means that  $S^2(X^6)$  is mapped in the same manner to  $S^2(M^4)$  and  $S^2(CP_2)$ .

One can imagine also correspondence with  $n$ -fold winding based on the identification  $(\theta_1, \phi_1) = (\theta_2, n\phi_2)$ . The area of  $S^2(M^4)$  are becomes  $n$ -fold and the  $S^2$  part of the Kähler action using  $\theta_2$  as coordinate transforms as  $S_K(S^2(M^4)n = 1) \rightarrow S_K(S^2(M^4)n) = n^2 S_K(S^2(M^4))$ .  $n = 1$  is the most plausible option physically.

2. What the proposed general vision implies for cosmological constant as a sum of  $S^2(M^4)$  and  $S^2(CP_2)$  parts of 6-D Kähler action giving in dimensional reduction 4-D volume term responsible for the cosmological constant and 4-D Kähler action. If the charge matrices of  $M^4$  and  $CP_2$  parts of Kähler form are orthogonal one can induce Kähler form. If the coupling to  $M^4$  Kähler form is imaginary,  $M^4$  and  $CP_2$  contributions to the total Kähler action have opposite signs.  $M^4$  and  $CP_2$  parts have opposite signs of magnetic terms and the sign of  $CP_2$  magnetic part is opposite to the volume term.
3. The dimensionally reduced action is obtained by integrating the 6-D Kähler action over  $S^2$  fiber. The integration gives the area  $A(S^2)$  of the  $S^2$  fiber, which in the metric induced from the spheres of twistor space of  $X^4$  is given by

$$A(S^2) = (1 + r^2)4\pi R^2(S^2(CP_2)) , \quad r = \frac{R(S^2(CP_2))}{R(S^2(M^4))} . \quad (4.6)$$

The very natural but un-checked assumption is that the radius of  $S^2(CP_2)$  equals to the radius  $R(CP_2)$  of the geodesic sphere of  $CP_2$ :

$$R(S^2(CP_2)) = R(CP_2) . \quad (4.7)$$

One obtains

$$L = -\frac{1}{16\pi\alpha_{K,6}} [J^2(CP_2) + \epsilon^2 J^2(M^4) + J^2(S^2(CP_2)) + \epsilon^2 J^2(S^2(M^4))] A(S^2) . \quad (4.8)$$

The immediate conclusion is that the phases of Kähler action and volume term are same so that the quantization condition for imaginary part of the action is not obtained.

4. The Kähler coupling strengths  $\alpha_K(CP_2)$  and  $\alpha_K(M^4)$  can be read from the first term

$$\begin{aligned} \frac{1}{\alpha_K(CP_2)} &= \frac{1}{\alpha_{K,4}4\pi(1+r^2)} \frac{R^2(CP_2)}{R^2} , \\ \frac{1}{\alpha_K(M^4)} &= \frac{\epsilon^2}{\alpha_K(CP_2)} . \end{aligned} \quad (4.9)$$

One can choose the factor  $R^2$  to be the area of  $S^2$  by suitably renormalizing  $1/\alpha_K$ . This would give simpler expression

$$\begin{aligned} \frac{1}{\alpha_K(CP_2)} &= \frac{1}{\alpha_{K,4}} , \\ \frac{1}{\alpha_K(M^4)} &= \frac{\epsilon^2}{\alpha_K(CP_2)} . \end{aligned} \quad (4.10)$$

5. One can deduce constraints on the value of the  $\epsilon^2$  from the smallness of the contributions of the corresponding  $U(1)$  gauge potential to the ordinary Coulomb potential affecting the energies of atoms by a coupling proportional to mass number  $A$  rather than  $Z$  as for Coulomb potential. This allows to distinguish between isotopes. This gives very stringent bounds on  $\epsilon^2$ . I have earlier derived an upper bound treating this term as a perturbation and by considering the contribution to the Coulomb energy of hydrogen atom [L4] (see <http://tinyurl.com/y8xcem2d>). One obtains  $\epsilon^2 \leq 10^{-10}$ . The upper bound is also the size scale of CP breaking induced by  $M^4$  part and characterizes also matter-antimatter asymmetry.

### 4.3.2 Cosmological constant

Consider next the prediction for the cosmological constant term.

1. The  $S^2$  parts of the actions have constant values. The natural normalization of Kähler form of  $J(S^2(X))$ ,  $X = M^4, CP_2$  is as  $J^2 = -2$ . This a convention is the overall scale of normalization can be chosen freely by rescaling  $1/\alpha_{K,4}$ . Taking into account the fact that index raising is carried out by induced metric one finds that the cosmological term given the sum of  $M^4$  and  $CP_2$  contributions to  $S^2$  part of Kähler action multiplied by  $A(S^2)$

$$\Lambda = \frac{1}{16\pi\alpha_K} \frac{2}{(1+r^2)R^2(CP_2)} \left(1 + \frac{\epsilon^2}{r^4}\right) . \quad (4.11)$$

If  $\epsilon$  is imaginary one can achieve the cancellation giving rise to small cosmological constant.

2. The empirical condition on cosmological constant (see [https://en.wikipedia.org/wiki/Cosmological\\_constant](https://en.wikipedia.org/wiki/Cosmological_constant)) can be expressed in terms of critical mass density corresponding to flat 3-space as

$$\begin{aligned} \Lambda &= 3\Omega_\Lambda H^2 , \quad \Omega \simeq .691 , \\ H &= \frac{da}{dt} a \quad \frac{da}{dt} = \frac{1}{\sqrt{g_{aa}}} . \end{aligned} \quad (4.12)$$



Here  $a$  corresponds to the proper time for the light-cone  $M_+^4$  and  $t$  for the proper time for the space-time surface, which is Lorentz invariant under the Lorentz group leaving the boundary  $\delta M_+^4$ .

From this one obtains a condition for allowing to get idea about the discrete evolution of  $\Lambda$  with p-adic length scale occurring in jumps:

$$1 + \frac{\epsilon^2}{r^4} = 24\pi\alpha_K(1+r^2)R^2(CP_2) \times \Omega_\Lambda H^2 . \quad (4.13)$$

In an excellent approximation one must have  $\epsilon \simeq r^2$ ,  $r = R(M^4)/(CP_2)$ . One can consider two obvious guesses. One has either  $R(M^4) = L_{Pl} = \sqrt{G}$  - that is Planck length - or one has the Compton length associated with Planck mass given by  $R(M^4) = 2\pi l_{Pl}$ . The first option gives in reasonable approximation  $r = 2^{-11}$  and  $\epsilon^2 = r^4 = 2^{-44} \sim .6 \times 10^{-13}$ . The second option gives  $\epsilon^2 \simeq .9 \times 10^{-10}$ . This values corresponds roughly to the  $CP_2$  breaking parameter and matter-antimatter asymmetry and  $M^4$  part of the Kähler action indeed gives rise to  $CP_2$  breaking. I have earlier derived an upper bound for  $\epsilon$  by demanding that the Kähler U(1) forces does not give rise to observable effects in the energy levels of hydrogen atom. The upper bound is of the same magnitude as the estimate for  $\epsilon^2$  for the Compton scale option.

3. If one accepts p-adic length scale hypothesis  $L_p \propto \sqrt{p}$ ,  $p \simeq 2^k$  [K14], one expects  $\Lambda(k) \propto 1/L(k)^2$  [K18] (see <http://tinyurl.com/ybrhguux>). How to achieve this? The only possibility is that the parameter  $\epsilon^2$  is subject to coupling constant evolution. One would have for the cosmological constant

$$\Lambda(k) \propto \frac{\epsilon^2}{r^4} - 1 \propto \frac{1}{L^2(k)} \propto 2^{-k} . \quad (4.14)$$

This would suggest for the 2-adic coupling constant evolution of  $\epsilon$  the expression

$$\epsilon^2 = -r^4(1 - X) , \quad X = 24\pi\alpha_K(1+r^2)R^2(CP_2) \times \Omega_\Lambda H^2 = q \times 2^{-k} . \quad (4.15)$$

where  $q$  is rational number. Note that from p-adic length scale hypothesis one has  $2^{-k} \propto 1/L^2(k)$ . One can consider also p-adic primes near powers of small prime in which case one obtains different evolution.

4. For  $\Omega_\Lambda$  constant this would predict quantization of Hubble constant as  $\Omega_\Lambda H^2 \propto 1/L(k)^2$  determined by naive scaling dimension. The ratio of Hubble constants for two subsequent scales would be  $H(k)/H(k+1) = \sqrt{2}$  if  $\Omega$  is constant. The observed - and poorly understood - variation of Hubble constant from cosmological studies and distance ladder studies is in the range 50 – 73.2 km/s/Mpc. Cosmological studies correspond to longer scales so that the smaller value of  $H$  is consistent with the decrease of  $H$ . The ratio of these upper and lower bounds is  $1.46 < \sqrt{2} \simeq 1.414$  (see <http://tinyurl.com/yd6m8sca> and <http://tinyurl.com/ycr4ffm4>).

**Remark:** The uncertainty in the value of Hubble constant is reflected as uncertainty in the distances  $D$  deduced from cosmic redshift  $z \simeq HD/c$ . This is taken into account in the definition of cosmological distant unit  $h^{-1}Mpc$ , where  $h$  is in the range .5 – .75 corresponding to a scale factor 1.5 rather near to  $\sqrt{2}$ .

5. Piecewise constant evolution means that acceleration parameter is positive since constant value of  $H$  gives

$$\frac{d^2 a}{dt^2} = \frac{(da/dt)^2}{a} = aH^2 > 0 . \quad (4.16)$$

If the phase transitions reducing  $H$  by factor 1/2 occur at  $a(k) = 2^{k/2}a_0$ , one has

$$\frac{d^2a}{dt^2} \propto 2^{-k/2} . \quad (4.17)$$

Acceleration would be reduced gradually with rate determined by its naive scaling dimension.

### 4.3.3 Solution of Hubble constant discrepancy from the length scale dependence of cosmological constant

One can criticize this proposal. The recent best values of the Hubble constant are 67.0 km/s/Mpc and 73.5 km/s/Mpc and their ratio is about 1.1 rather than  $\sqrt{2}$ . Therefore the hypothesis that  $H$  satisfies p-adic length scale hypothesis might be too strong. In the following a proposal in which the variation of  $H$  could be due to the variation of cosmological constant  $\Lambda$  satisfying p-adic length scale hypothesis is discussed.

The discrepancy of the two determinations of Hubble constant has led to a suggestion that new physics might be involved (see <http://tinyurl.com/yabszweg>).

1. Planck observatory deduces Hubble constant  $H$  giving the expansion rate of the Universe from CMB data something like 360,000 y after Big Bang, that is from the properties of the cosmos in long length scales. Riess's team deduces  $H$  from data in short length scales by starting from galactic length scale and identifies standard candles (Cepheid variables), and uses these to deduce a distance ladder, and deduces the recent value of  $H(t)$  from the redshifts.
2. The result from short length scales is 73.5 km/s/Mpc and from long scales 67.0 km/s/Mpc deduced from CMB data. In short length scales the Universe appears to expand faster. These results differ too much from each other. Note that the ratio of the values is about 1.1. There is only 10 percent discrepancy but this leads to conjecture about new physics: cosmology has become rather precise science!

TGD could provide this new physics. I have already earlier considered this problem but have not found really satisfactory understanding. The following represents a new attempt in this respect.

1. The notions of length scale and fractality are central in TGD inspired cosmology. Many-sheeted space-time forces to consider space-time always in some length scale and p-adic length scale defined the length scale hierarchy closely related to the hierarchy of Planck constants  $h_{eff}/h_0 = n$  related to dark matter in TGD sense. The parameters such as Hubble constant depend on length scale and its value differ because the measurements are carried out in different length scales.
2. The new physics should relate to some deep problem of the recent day cosmology. Cosmological constant  $\Lambda$  certainly fits the bill. By theoretical arguments  $\Lambda$  should be huge making even impossible to speak about recent day cosmology. In the recent day cosmology  $\Lambda$  is incredibly small.
3. TGD predicts a hierarchy of space-time sheets characterized by p-adic length scales ( $Lk$ ) so that cosmological constant  $\Lambda$  depends on p-adic length scale  $L(k)$  as  $\Lambda \propto 1/GL(k)^2$ , where  $p \simeq 2^k$  is p-adic prime characterizing the size scale of the space-time sheet defining the sub-cosmology. p-Adic length scale evolution of Universe involve as sequence of phase transitions increasing the value of  $L(k)$ . Long scales  $L(k)$  correspond to much smaller value of  $\Lambda$ .
4. The vacuum energy contribution to mass density proportional to  $\Lambda$  goes like  $1/L^2(k)$  being roughly  $1/a^2$ , where  $a$  is the light-cone proper time defining the "radius"  $a = R(t)$  of the Universe in the Robertson-Walker metric  $ds^2 = dt^2 - R^2(t)d\Omega^2$ . As a consequence, at long length scales the contribution of  $\Lambda$  to the mass density decreases rather rapidly.

Must however compare this contribution to the density  $\rho$  of ordinary matter. During radiation dominated phase it goes like  $1/a^4$  from  $T \propto 1/a$  and from small values of  $a$  radiation

dominates over vacuum energy. During matter dominated phase one has  $\rho \propto 1/a^3$  and also now matter dominates. During predicted cosmic string dominated asymptotic phase one has  $\rho \propto 1/a^2$  and vacuum energy density gives a contribution which is due to Kähler magnetic energy and could be comparable and even larger than the dark energy due to the volume term in action.

5. The mass density is sum  $\rho_m + \rho_d$  of the densities of matter and dark energy. One has  $\rho_m \propto H^2$ .  $\Lambda \propto 1/L^2(k)$  implies that the contribution of dark energy in long length scales is considerably smaller than in the recent cosmology. In the Planck determination of  $H$  it is however assumed that cosmological constant is indeed constant. The value of  $H$  in long length scales is under-estimated so that also the standard model extrapolation from long to short length scales gives too low value of  $H$ . This is what the discrepancy of determinations of  $H$  performed in two different length scales indeed demonstrate.

A couple of remarks are in order.

1. The twistor lift of TGD [K11, K18] [L11] suggests an alternative parameterization of vacuum energy density as  $\rho_{vac} = 1/L^4(k_1)$ .  $k_1$  is roughly square root of  $k$ . This gives rise to a pair of short and long p-adic length scales. The order of magnitude for  $1/L(k_1)$  is roughly the same as that of CMB temperature  $T$ :  $1/L(k_1) \sim T$ . Clearly, the parameters  $1/T$  and  $R$  correspond to a pair of p-adic length scales. The fraction of dark energy density becomes smaller during the cosmic evolution identified as length scale evolution with largest scales corresponding to earliest times. During matter dominated era the mass density going like  $1/a^3$  would to dominate over dark energy for small enough values of  $a$ . The asymptotic cosmology should be cosmic string dominated predicting  $1/GT^2(k)$ . This does not lead to contradiction since Kähler magnetic contribution rather than that due to cosmological constant dominates.
2. There are two kinds of cosmic strings: for the other type only volume action is non-vanishing and for the second type both Kähler and volume action are non-vanishing but the contribution of the volume action decreases as function of the length scale.

## 5 Further comments about classical field equations in TGD framework

In the sequel some remarks about field equations defining space-time surfaces in TGD framework are made.

First three dualities at the level of field equations are discussed. These dualities are rather obvious but extremely important concerning the physical interpretation of TGD.

The earlier proposal that external particles correspond to minimal surfaces is strengthened. Also the interaction regions would correspond to minimal surfaces and minimal surface property would break down only at reaction vertices associated with partonic 2-surfaces defining the 2-D counterparts of vertices: this would mean physical exchange of classical conserved charges between volume part of the action and Kähler action just at these points.

This would mean strengthening of the strong form of holography to  $M^4 \times CP_2$  counterpart of the proposed number theoretic holography based on the notion of cognitive representation at the level of  $M^8$  [L5] and also justification for the proposed construction of twistor Grassmannian variants of scattering amplitudes involving also data at a discrete set of points [L12].

### 5.1 Three dualities at the level of field equations

The basic field equations of TGD allow several dualities. There are 3 of them at the level of basic field equations (and several other dualities such as  $M^8 - M^4 \times CP_2$  duality).

1. The first duality is the analog of particle-field duality. The spacetime surface describing the particle (3-surface of  $H = M^4 \times CP_2$  instead of point-like particle) corresponds to the particle aspect whereas the fields inside it geometrized in terms of sub-manifold geometry correspond to the field aspect. Particle orbit serves as wave guide for field, one might say.

2. Second duality is particle-spacetime duality. Particle identified as 3-D surface means that particle orbit is space-time surface glued to a larger space-time surface by topological sum contacts. It depends on the scale used, whether it is more appropriate to talk about particle or of space-time.
3. The third duality is hydrodynamics- massless field theory duality. Hydrodynamical equations state local conservation of Noether currents. Field equations indeed reduce to local conservation conditions of Noether currents associated with the isometries of  $H$ . On the other hand, these equations have interpretation as non-linear geometrization of massless wave equation with coupling to Maxwell fields. This realizes the ultimate dream of theoretician: symmetries dictate the dynamics completely. This is expected to be realized also at the level of scattering amplitudes and the generalization of twistor Grassmannian amplitudes could realize this in terms of Yangian symmetry.

Hydrodynamics-wave equations duality generalizes to the fermionic sector and involves super-conformal symmetry.

1. What I call modified gamma matrices  $\Gamma^\alpha$  are obtained as contractions of the partial derivatives of the action defining space-time surface with respect to the gradients of imbedding space coordinate with imbedding space gamma matrices [K13]. The divergence  $D_\alpha \Gamma^\alpha$  vanishes by field equations for the space-time surface and this is necessary for the internal consistency the Dirac equation ( $\bar{\Psi}$  satisfies essentially the same equation as  $\Psi$ ).  $\Gamma^\alpha$  reduce to ordinary ones if the space-time surface is  $M^4$  and one obtains ordinary massless Dirac equation.
2. Modified Dirac equation [K13] expresses conservation of super current and actually infinite number of super currents obtained by contracting second quantized induced spinor field with the solutions of modified Dirac. This corresponds to the super-hydrodynamic aspect. On the other hand, modified Dirac equation corresponds to fermionic analog of massless wave equation.

## 5.2 Are space-time surfaces minimal surfaces everywhere except at 2-D interaction vertices?

The action  $S$  determining space-time surfaces as preferred extremals follows from twistor lift [K11, K20, K18, L12] and equals to the sum of volume term  $Vol$  multiplied by the TGD counterpart of cosmological constant and Kähler action  $S_K$ . The field equation is a geometric generalization of d'Alembert (Laplace) equation in Minkowskian (Euclidian) regions of space-time surface coupled with induced Kähler form analogous to Maxwell field. Generalization of equations of motion for particle by replacing it with 3-D surface is in question and the orbit of particle defines a region of space-time surface.

1. Zero energy ontology (ZEO) suggests that the external particles arriving to the boundaries of given causal diamond (CD) are like free massless particles and correspond to minimal surfaces as a generalization of light-like geodesic. This dynamic reduces to mere algebraic conditions and there is no dependence on the coupling parameters appearing in  $S$ . In contrast to this, in the interaction regions inside CDs there could be a coupling between  $Vol$  and  $S_K$  due to the non-vanishing divergences of energy momentum currents associated with the two terms in action cancelling each other.
2. Similar algebraic picture emerges from  $M^8 - H$  duality [L5] at the level of  $M^8$  and from what is known about preferred extremals of  $S$  assumed to satisfy infinite number of super-symplectic gauge conditions at the 3-surfaces defining the ends of space-time surface at the opposite boundaries of CD.

At  $M^8$  side of  $M^8 - H$  duality associativity is realized as quaternionicity of either tangent or normal space of the space-time surface. The condition that there is 2-D integral distribution of sub-spaces of tangent spaces defining a distribution of complex planes as subspaces of octonionic tangent space implies the map of the space-time surface in  $M^8$  to that of  $H$ . Given point  $m_8$  of  $M^8$  is mapped to a point of  $M^4 \times CP_2$  as a pair of points  $(m_4, s)$  formed

by  $M^4 \subset M^8$  projection  $m_4$  of  $m_8$  point and by  $CP_2$  point  $s$  parameterizing the tangent space or the normal space of  $X^4 \subset M^8$ .

**Remark:** The assumption about integrable distribution of  $M^2(x)$  defining string world sheet in  $M^4$  might be too general:  $M^2(x)$  could not depend on  $x$ .

If associativity or even the condition about the existence of the integrable distribution of 2-planes fails, the map to  $M^4 \times CP_2$  is lost. One could cope with the situation since the gauge conditions at the boundaries of CD would allow to construct preferred extremal connecting the 3-surfaces at the boundaries of CD if this kind of surface exists at all. One can however wonder whether giving up the map  $M^8 \rightarrow H$  is necessary.

3. Number theoretic dynamics in  $M^8$  involves no action principle and no coupling constants, just the associativity and the integrable distribution of complex planes  $M^2(x)$  of complexified octonions. This suggests that also the dynamics at the level of  $H$  involves coupling constants only via boundary conditions. This is the case for the minimal surface solutions suggesting that  $M^8 - H$  duality maps the surfaces satisfying the above mentioned conditions to minimal surfaces. The universal dynamics conforms also with quantum criticality.
4. One can argue that the dependence of field equations on coupling parameters of  $S$  leading to a perturbative series in coupling parameters in the interior of the space-time surface inside CD spoils the extremely beautiful purely algebraic picture about the construction of solutions of field equations using conformal invariance assignable to quantum criticality. Classical perturbation series is also in conflict with the vision that the TGD counterparts twistorial Grassmannian amplitudes do not involve any loop contributions coming as powers of coupling constant parameters [L12].

To sum up, both  $M^8 - H$  duality, number theoretic vision, quantum criticality, twistor lift of TGD reducing dynamics to the condition about the existence of induced twistor structure, and the proposal for the construction of twistor scattering amplitudes suggest an extremely simple picture about the situation. The divergences of the energy momentum currents of  $Vol$  and  $S_K$  would be non-vanishing delta function type singularities only at discrete points at partonic 2-surfaces defining generalized vertices so that minimal surface equations would hold almost everywhere as the original proposal indeed stated.

1. The fact that all the known extremals of field equations for  $S$  are minimal surfaces conforms with the idea. This might be due to the fact that these extremals are especially easy to construct but could be also true quite generally apart from singular points. The divergences of the energy momentum currents associated with  $S_K$  and  $Vol$  vanish separately: this follows from the analog of holomorphy reducing the field equations to purely algebraic conditions.

It is essential that Kähler current  $j_K$  vanishes or is light-like so that its contraction with the gradients of the imbedding space coordinates vanishes. Second condition is that in transversal degrees of freedom energy momentum tensor is tensor of form (1,1) in the complex sense and second fundamental form consists of parts of type (1,1) and (-1,-1). In longitudinal degrees of freedom the trace  $H^k$  of the second fundamental form  $H^k_{\alpha\beta} = D_\beta \partial_\alpha h^k$  vanishes.

2. Minimal surface equations are a non-linear analog of massless field equation but one would like to have also the analog of massless particle. The 3-D light-like boundaries between Minkowskian and Euclidian space-time regions are indeed analogs of massless particles as are also the string like world sheets, whose exact identification is not yet fully understood. In any case, they are crucial for the construction of scattering amplitudes in TGD based generalization of twistor Grassmannian approach. At  $M^8$  side these points could correspond to singularities at which Galois group of the extension of rationals has a subgroup leaving the point invariant. The points at which roots of polynomial as function of parameters co-incide would serve as an analog.

The intersections of string world sheets with the orbits of partonic 2-surface are 1-D light-like curves  $X^1_L$  defining fermion lines. The twistor Grassmannian proposal [L12] is that the ends of the fermion lines at partonic 2-surfaces defining vertices provide the information needed to construct scattering amplitudes so that information theoretically the construction

of scattering amplitudes would reduce to an analog of quantum field theory for point-like particles.

3. Number theoretic vision discretizes coupling constant evolution: the values of coupling constants are labelled by parameters of extension of rationals and p-adic primes. This implies that twistor scattering amplitudes for given discrete values of coupling constants involve no radiative corrections [L12]: the construction of twistor Grassmannian amplitudes would be extremely simple. Note that infinite perturbation series would break the expression of scattering amplitudes as rational functions with coefficients in the extension of rationals defining the adèle [L6, L7]. The cuts for the scattering amplitudes would be replaced by sequences of poles. This is unavoidable also because there is number theoretical discretization of momenta from the condition that their components belong to an extension of rationals defining the adèle.

What could the reduction of cuts to poles for twistorial scattering amplitudes at the level of momentum space [L12] mean at space-time level?

1. Poles of an analytic function are co-dimension 2 objects. d'Alembert/Laplace equations holding true in Minkowskian/Euclidian signatures express the analogs of analyticity in 4-D case. Co-dimension 2 rule forces to ask whether partonic 2-surfaces defining the vertices and string world sheets could serve analogs of poles at space-time level? In fact, the light-like orbits  $X_L^3$  of partonic 2-surfaces allow a generalization of 2-D conformal invariance since they are metrically 2-D so that  $X_L^3$  and string world sheets could serve in the role of poles.

$X_L^3$  could be seen as analogs of orbits of bubbles in hydrodynamical flow in accordance with the hydrodynamical interpretations. Particle reactions would correspond to fusions and decays of these bubbles. Strings would connect these bubbles and give rise to tensor networks and serve as space-time correlates for entanglement. Reaction vertices would correspond to common ends for the incoming and outgoing bubbles. They would be analogous to the lines of Feynman diagram meeting at vertex: now vertex would be however 2-D partonic 2-surface.

2. What can one say about the singularities associated with the light-like orbits of partonic 2-surfaces? The divergence of the Kähler part  $T_K$  of energy momentum current  $T$  is proportional to a sum of contractions of Kähler current  $j_K$  with gradients  $\nabla h^k$  of  $H$  coordinates.  $j_K$  need not be vanishing: it is enough that its contraction with  $\nabla h^k$  vanishes and this is true if  $j_K$  is light-like. This is the case for so called massless extremals (MEs). For the other known extremals  $j_K$  vanishes.

Could the Kähler current  $j_K$  be light-like and non-vanishing and singular at  $X_L^3$  and at string world sheets? This condition would provide the long sought-for precise physical identification of string world sheets. This would also induce to the modified Dirac action a 2-D contribution. Minimal surface equations would hold true also at these two kinds of surfaces apart from possible singular points. Even more:  $j_K$  could be non-vanishing and thus also singular only at the 1-D intersections  $X_L^1$  of string world sheets with  $X_L^3$  - I have called these curves fermionic lines.

What it means that  $j_K$  is singular - that is has 2-D delta function singularity at string world sheets?  $j_K$  is defined as divergence of the induced Kähler form  $J$  so that one can use the standard definition of derivative to define  $j_K$  at string world sheet as the limiting value  $j_K^\alpha = (Div_{+-} J)^\alpha = \lim_{\Delta x^n \rightarrow 0} (J_+^{\alpha n} - J_-^{\alpha n})/\Delta x^n$ , where  $x^n$  is a coordinate normal to the string world sheet. If  $J$  is discontinuous, this gives rise to a singular current located at string world sheet. This current should be light like to guarantee that energy momentum currents are divergenceless. If  $J$  is not light-like, it gives rise to isometry currents with non-vanishing divergence at string world sheet. This is guaranteed if the isometry currents  $T^{\alpha A}$  are continuous through the string world sheet.

3. If the light-like  $j_K$  at partonic orbits is localized at fermionic lines  $X_L^1$ , the divergences of isometry currents could be non-vanishing and singular only at the vertices defined at partonic 2-surfaces at which fermionic lines  $X_L^1$  meet. The divergences  $Div T_K$  and  $Div T_{Vol}$  would be non-vanishing only at these vertices. They should of course cancel each other:  $Div T_K = -Div T_{Vol}$ .

4.  $DivT_K$  should be non-vanishing and singular only at the intersections of string world sheets and partonic 2-surfaces defining the vertices as the ends of fermion lines. How to translate this statement to a more precise mathematical form? How to precisely define the notions of divergence at the singularity?

The physical picture is that there is a sharing of conserved isometry charges of the incoming partonic orbit  $i = 1$  determined  $T_K$  between 2 outgoing partonic orbits labelled by  $j = 2, 3$ . This implies charge transfer from  $i = 1$  to the partonic orbits  $j = 2, 3$  such that the sum of transfers sum up to to the total incoming charge. This must correspond to a non-vanishing divergence proportional to delta function. The transfer of the isometry charge for given pair  $i, j$  of partonic orbits that is  $Div_{i \rightarrow j} T_K$  must be determined as the limiting value of the quantity  $\Delta_{i \rightarrow j} T_K^{\alpha, A} / \Delta x^\alpha$  as  $\Delta x^\alpha$  approaches zero. Here  $\Delta_{i \rightarrow j} T_K^{\alpha, A}$  is the difference of the components of the isometry currents between partonic orbits  $i$  and  $j$  at the vertex. The outcome is proportional delta function.

5. Similar description applies also to the volume term. Now the trace of the second fundamental form would have delta function singularity coming from  $Div_{i \rightarrow j} T_K$ . The condition  $Div_{i \rightarrow j} T_K = -Div_{i \rightarrow j} T_{Vol}$  would bring in the dependence of the boundary conditions on coupling parameters so that space-time surface would depend on the coupling constants in accordance with quantum-classical correspondence. The manner how the coupling constants make themselves visible in the properties of space-time surface would be extremely delicate.

This picture conforms with the vision about scattering amplitudes at both  $M^8$  and  $H$  sides of  $M^8 - H$  duality.

1.  $M^8$  dynamics based on algebraic equations for space-time surfaces [L5] leads to the proposal that scattering amplitudes can be constructed using the data only at the points of space-time surface with  $M^8$  coordinates in the extension of the rationals defining the adèle [L7, L6]. I call this discrete set of points cognitive representation with motivations coming from TGD inspired theory of consciousness [K7].
2. At  $H$  side the information theoretic interpretation would be that all information needed to construct scattering amplitudes would come from points at which the divergences of the energy momentum tensors of  $S_K$  and  $Vol$  are non-vanishing and singular.

Both pictures would realize extremely strong form of holography, much stronger than the strong form of holography that stated that only partonic 2-surfaces and string world sheets are needed.

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