Comparing the S-matrix descriptions of fundamental interactions provided by standard model and TGD

July 6, 2026

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Abstract

The construction of S-matrix has been a long-standing challenge of TGD and during years I have considered numerous proposals. Holography= holomorphy vision (H-H) allows solving the classical field equations for space-time surfaces exactly.

The Dirac equation in $H = M^4 \times CP_2$ can be solved exactly for M^4. If M^4 has Kähler structure color confinement can be understood in terms of the H Dirac equation alone since the M^4 Dirac equation allows tachyonic masses and 8-D massless condition allows to construct light states, which must be color singlets. The interaction between space-time surfaces, which by H-H represent particles, is naturally a contact interaction occurring in their intersection consisting of string world sheets if the space-time surfaces have the same Hamilton-Jacobi structure.

The basic structure of QCD generalizes. All external particles are analogous to hadronic phase. Interactions occur in the color deconfined phase governed by the induced/modified Dirac equation. Color- and electroweak interactions can be seen as aspects of the same interaction. At the level of H, color partial waves as representations of the color group SU(3) are analogous to orbital angular momentum eigenstates. Electroweak group U(2) is a subgroup of the color group acting as gauge transformations and color interactions at this level can be identified as electroweak interactions. The value of color coupling strength is predicted correctly.

The basic objection against TGD has been that there are new indications for the new physics from LHC. Quite recently it was however reported there is evidence for anomalies related to the transition to a phase that has been interpreted as quark gluon plasma. Intriguingly, the new physics predicted by TGD indeed relates to this transition.

Contents

1 Introduction

The construction of S-matrix has been a long-standing challenge of TGD and during years I have considered numerous proposals.

1. The first naive attempts were based on a naive generalization of path integral but it became clear path integral simply fails to exist. This led to the discovery of the notion "world of classical worlds" (WCW) consisting of 3-surfaces to which one can assign a highly unique space-time surface: this means almost-deterministic holography. Quantum states would be spinor fields in WCW.

2. The geometrization of WCW is highly unique already in the case of loop spaces from the existence of the Riemann connection [K8, K4, K15, K17]. The conformal symmetries and Kac-Moody symmetries generalize in the TGD framework to a huge generalization of super-conformal symmetries and to super symplectic symmetry and WCW can be seen as a union of analogs of symmetric spaces labelled by zero modes not appearing in the metric.

   The condition that the S-matrix is invariant under these huge symmetries gives excellent hopes that the S-matrix is highly unique. The tough problem is to construct it and mere symmetry arguments are not enough to achieve this.

   This raised the hope that TGD is unique from its mathematical existence. The existence of the twistor lift of TGD indeed leaves only the option $H = M^4 \times CP_2$ since only M^4 and CP_2 allow twistor space with Kähler structure [A2].

3. In TGD fermions are the only fundamental elementary particles and classical fields are obtained by inducing non-dynamic geometric objects to the space-time surfaces. This means a huge simplification since all elementary particles consist of fundamental fermions. The spinor structure at the space-time surface is induced, which means simply restriction of the second quantized free spinor fields of H and identification of induced gamma matrices as projections of H gamma matrices.

   This implies that fermionic propagators are simply restrictions of free H-propagators to the space-time surfaces. But How to get various vertices, in particular pair creation vertex, when one only free fermions are available? The idea is that fermion pair creation and scattering takes place in the classical induced field, essentially in the same way as in path integral approach.

   There is also a second tough problem. How to get pair creation for free fermions. The solution is simple: creation of a fermion pair means that the fermion turns backwards in time or more generally, the fermion line has an edge. Exotic smooth structures [A3, A4, A1] obtained from the standard smooth structure by adding defects is a completely unique feature of 4-dimensional spaces. The proposal is that the vertices as edges of fermion lines correspond to defects of the standard smooth structure [L22, L10, L27]. Quantum theory would be possible only for 4-D space-times. Wheeler would say that one has interactions without interactions.

4. Few years ago holography = holomorphy vision (H-H) emerged [L19, L28, L14, L37] and provided a general solution of field equations for space-time surfaces involving only solution of local algebraic equations: TGD is exactly solvable. Space-time surfaces are minimal surfaces and can be seen as analogs of solution of massless field equations. Any general coordinate invariant action principle constructible in terms of induced geometry gives the same space-time surfaces and only the boundary conditions, if even these, depend on the variational principle. Number theoretic vision suggests that the vacuum functional is expressible in terms of number theoretic invariants.

5. H-H led also to an exact general solution of the Dirac equation for the induced spinors in X^4 in terms of holography [L33, L31], very much the same way as in string models. So that Dirac equation can be solved both at the level of H and X^4. Apart from the right-handed neutrino, all modes of H spinor field have CP_2 mass scale.

   However, if M^4 has Kähler structure, one can have modes with negative M^4 mass squared but the total mass squared must vanish for on mass shell states. One can construct many fermion states with vanishing (additive) M^4 mass squared. This requires color singlet property meaning color confinement. All light external particles, both hadrons, leptons, gauge bosons, and gravitons would be in these kinds of states.

These latest advances led to a quite dramatic increase in the understanding of how the TGD view of standard model physics and gravitation differs from the standard view.

1. All interactions reduce to the dynamics of 3-surfaces obeying holography = holomorphy principle [L19, L28, L14, L37] and by general coordinate invariance only 4 H-coordinates define the primary dynamical variables at the fundamental level.

2. The study of the induced Dirac equation led to a generalization of the QCD type description involving deconfinement and hadronization so that it applies quite generally. External states correspond to many particle states constructed from the modes of the H Dirac equation. In interactions, the hadrons transform to a deconfined quark phase at X^4 in which quarks obey the induced Dirac equation and behave like massless fermions. This applies also to leptons, which also can move in color partial waves.

3. Electroweak and strong interactions can be seen as different aspects of the same interaction. Color partial waves in H are analogous to orbital angular momentum states and since the electroweak group can be regarded as a subgroup of $SU(3)$, electroweak quantum numbers can be regarded as color quantum numbers analogous to spin. "Strong-electroweak" is completely analogous to "orbital angular momentum-spin".

   $CP_2 = SU(3)/U(2)$ states that also geometrically $U(2)$ acts like a gauge group, whereas $SU(3)$ is not a gauge group. In electroweak degrees of freedom confinement occurs only for SU(2) but not for electromagnetic U(1) and takes place by screening of electroweak isospin but pairs of left and right-handed neutrinos. The estimate for color coupling strength comes out correctly [L31].

4. By H-H, the X^4 spinor modes are analogous to the spin states of a point-like particle. The interaction of two space-time surfaces occurs in the interaction of the particle- like 4-surfaces consisting of string world sheets for identical H-J structures [L36]. This is nothing but the analog for the collision of point-like particles.

2 TGD view of standard model physics and hadron physics in particular

The study of the solution spectrum of Dirac equations in H and X^4 has led to a quite dramatic increase of the understanding of how TGD view of standard model physics and gravitation differs from the standard view. All interactions reduce to the dynamics of 3-surfaces obeying holography = holomorphy principle and by general coordinate invariance only 4 H-coordinates define the primary dynamical variables at the fundamental level.

In particular, in TGD electroweak and strong interactions can be seen as different aspects of the same interaction. Color partial waves in H are analogous to orbital angular momentum states and since the electroweak group can be regarded as a subgroup of $SU(3)$, electroweak quantum numbers can be regarded as color quantum numbers analogous to spin. "Strong-electroweak" is completely analogous "orbital angular momentum-spin" $CP_2 = SU(3)/U(2)$ states that also geometrically $U(2)$ acts like a gauge group, whereas $SU(3)$ is not a gauge group. In electroweak degrees of freedom confinement occurs only for SU(2) but not for electromagnetic U(1) and takes place by screening of electroweak isospin but pairs of left and right-handed neutrinos. The estimate for color coupling strength comes out correctly.

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2.1 How could the transitions between hadronic and quark phases occur in the TGD framework?

The solutions of the ordinary Dirac equation in H with M^4 Kähler structure have masses of order CP_2 and light states are color singlets whereas the solutions of the induced/modified Dirac equation for quarks in X^4 are massless. In the case of quarks this suggests an interpretation in terms of hadrons and massless quarks. This picture also applies to leptons.

The QCD description of hadronic reactions is statistical and is in terms of quark and gluon distribution functions characterizing hadrons and fragmentation functions to hadrons for quarks and gluons. What could the TGD counterparts of these functions be and could an analogous description at quantum level be possible? What happens in the transitions hadron phase and free quark phase and how to describe this in TGD?

2.1.1 Hadron phase $\leftrightarrow$ quark phase transition as a transition between phases characterized by $8-D$ and $4-D$ masslessness

In the transition to the X^4 phase with free massless quarks, the colored H spinor modes are replaced with holomorphic X^4 spinor modes. The opposite transition takes place in hadronization. $X^4 \rightarrow H$ transition is analogous with the Higgs mechanism in which transition occurs from a massless phase to a massive phase (in M^4 sense). Transition is also between deconfined and confined phases. This description applies also to leptons which also move in H spinor partial waves.

A more general view is based on the breaking of 4-D generalization of conformal symmetry. In hadronization $4-D$ light-likeness is replaced with 8-D light-likeness in H. Propagation takes place along the space-time surface and the propagator is determined by the induced/modified Dirac operator. What is of crucial importance is that fermionic oscillator operators for the induced spinors fields are expressed in terms of those for the H spinor field.

What about the description of color in the X^4 phase? Does one obtain color triplets in the holomorphic basis? Could the color partial waves $\{\xi_1, \xi_2, 1\}$ proportional form a counterpart of color triplet? Could the color triplet correspond to the 3 coordinate patches for the complex structure of CP_2 as a complex projective space? Why are color triplets special for quarks and color singlets for leptons? Does this relate to generalized conformal invariance, which could make higher partial waves gauge degrees of freedom and imply the analog of gauge invariance of QCD? What about Kac-Moody type gauge invariance? Could fixed H spinor modes as ground states for Kac-Moody representations: this would imply that each scaled variant of hadron physics associated with hadrons for particle color partial waves for H Dirac equation would defines its own TGD counterpart of perturbative QCD or of string model description.

2.1.2 Quantum measurement theory in ZEO as a guideline

Quantum measurement can be seen as a Hilbert space projection. Could this projection be induced by a geometric projection from H to the space-time surface for the spinor modes. Does it take place always in the interaction and how this interaction is realized?

The modes of the X^4 Dirac operator have a fixed M^4 chirality and this is the signature of masslessness. Apart from the covariantly constant right-handed neutrino, H modes have only a fixed H chirality and are therefore massive. Therefore also M^4 chirality would be measured in the transition to the quark phase. Note that also projections to lower dimensional surfaces, such as partonic orbits, string world sheets and fermion lines make sense if this interpretation is correct. In this picture, the overlap between H modes and X^4 modes would characterize the transition from hadrons to quarks and vice versa.

The ZEO based description of any particle reaction involves a pair of BSFRs. In the case of hadronic reactions this would involve the transition of hadrons to quarks in BSFR, time evolution with opposite arrow of time, and second BSFR leading from quark phase to hadron phase.

1. In ZEO, the deconfinement phase transition $H \rightarrow X^4$ from hadron to quark phase would involve a localization from H to X^4. This also means a localization in the "world of classical worlds" (WCW). In the deconfined state localized to single X^4, one would have an analog of QFT in a fixed background space-time. Note however that every 3-surface defines its own space-time surface as its Bohr orbit, which is however not quite unique, which in fact forces

ZEO. Therefore one has a superposition of scattering amplitudes over the space-time surfaces satisfying holography= holomorphy principle.

2. Hadronization as a transition $X^4 \rightarrow H$ would in turn mean a delocalization in WCW and could be interpreted as a localization in the analog of momentum space for WCW. The observables measured would be quantum numbers of WCW spinor modes. This includes measurement of H quantum numbers but the light states are color singlet many fermion states. Color partial waves have the CP_2 mass scale.

2.1.3 What does the interaction of particles as space-time surfaces mean?

What does the interaction of particles as space-time surfaces obeying holography= holomorphy principle mean? When do the particle interactions lead to the transition to the phase corresponding to a localization in WCW? In strong interactions this kind of interaction requires a high collision energy implying that the interactions occur in a scale smaller than the geometric size scale of the colliding particles so that the internal geometric structure of the particle become visible. In the TGD framework, these details naturally correspond to lower dimensional structure consisting of the light-like parton orbits and string world sheets having their boundaries at the parton orbits. Note that this picture might apply to to all interactions. Topological considerations allow to make this picture rather concrete [L36].

1. For topological reasons, the intersection of the generic space-time surfaces is a discrete set of points. The systems should fuse somehow and form a quantum coherent interaction region. If the H-J structures of the space-time surfaces are identical meaning that in the interaction region both space-time surfaces have the same coordinates (u, v, w, ξ_1, ξ_2), the intersection is 2-D string world sheet, containing point-like fermions as fermion lines at its boundaries assignable to light-like 3-D parton orbit [L37]. This makes possible a string model type description for the interactions of the fundamental fermions. By the hypercomplex holomorphy, the description would be rather simple since the second light-like coordinate of the string world sheet is non-dynamical.

2. Only fermions and their bound states appear as fundamental quantum objects in the TGD framework. If they emerge in the formation of states delocalized in WCW they would correspond to hadrons, leptons and electroweak bosons. In particular, bosons as incoming and outgoing are identified as bound states of fermions and antifermions. The stringy view of the interactions implies that bosons need not appear at all in the deconfined phase.

   If so, there would be no gluons and the fundamental vertex would correspond to a creation or annihilation of a fermion pair from "vacuum" and the classical induced gauge fields would define the vertices. This would take place when string world sheets fuse or split and a pair of fermion lines at separate string world sheets is created or disappears.

3. The notion of exotic smooth structure [A3, A4, A1] possible only in 4-D space-time and reducing to the standard smooth structure apart from defects identifiable as this kind of singularities allows these kinds of edges [L22, L10, L27]. This allows also to consider scattering events in which the fermion line has an edge serving as vertex giving rise to momentum exchange. These edges would correspond to failure of holomorphy at a single point.

2.1.4 The relationship between the oscillator operators of spinor modes in H and X^4

It is possible to express X^4 oscillator operators in terms of H oscillator operators [K21]. Induction means the restriction of the mode expansion of the second quantized H spinor field to the space-time surface X^4. Similar expansion for X^4 spinor field in terms of conformal modes makes sense. The two representations must be identical. This implies that the oscillator operators at X^4 are expressible as inner products of conformal modes and H spinor field. H oscillator operators are fundamental and no separate second quantization at X^4 is needed.

The inner products between the spinor modes of X^4 and H involve an integration over the space-time surface or a lower-dimensional space-time region. By the 8-D chiral symmetry the matrix element must involve gamma matrices and reduce to an integral of an inner product of the conformal mode of the induced Dirac operator with the fermionic super current over the parton orbit. The 3-D intersection of the space-time surface with the light-like boundary of CD cannot be excluded. The integral over the parton orbit is natural since the transversal hypercomplex coordinate for the associated string world sheet is not dynamical.

Overlap integrals between the c-number valued modes of X^4 spinor field and the second quantized H spinor field give X^4 oscillator operators in terms of H oscillator operators. These integrals characterize the transition between the two phases and its reversal and would replace the parton distribution functions and fragmentation functions in TGD. The conservation of color quantum numbers and corresponding M^4 quantum numbers in holomorphic basis in which X^4 complex coordinates correspond to those of H.

What about propagators in the quark phase? The propagation would be restricted to X^4 rather than occurring in H. X^4 spinor field would be defined as the sum over its conformal modes and the Dirac propagator would be defined as a two point function, which can be calculated because oscillator operators are expressible in terms of H oscillator operators.

2.1.5 Description of hadron reactions in ZEO

As found, zero energy ontology and holomorphy= holography vision suggest a universal description of all particle reactions. The particle reaction involves a temporary time reversal involving two BSFRs.

1. In the first BSFR a projection from the space of hadron states in H to free many-quark states in X^4 would occur. This localization in WCW would also involve a measurement of M^4 chirality by an external observer. The resulting state would consist of free massless quarks in X^4 and evolve by SSFRs backwards in geometric time. The interactions would be mediated by string world sheets having fermion lines at their boundaries and the notion of exotic smooth structure would be essential making possible fermion scattering and pair creation in the absence of fundamental bosonic quantum fields.

2. After that a second BSFR would occur inducing a delocalization in WCW and a hadronic state would emerge and evolve by SSFRs. One can say that the states delocalized in WCW correspond to hadrons (and quite generally color singlet states). WCW observables, which include the observables associated with H, would be measured. Concerning the calculation of the scattering amplitudes, this means that the quark oscillator oscillator operators would be expressed in terms of H oscillator operators and a Hilbert space projection to a state of hadrons would take place.

2.2 A more detailed vision stimulated by the analysis of LLM session

Recently Marko Manninen performed a LLM session using OpenAI's O3 language model (GPT hitherto) using prompts related to the geometric aspects of TGD: the results can be found in the article by Marko and me [L42]. Due to its "education", GPT grave misunderstandings and at the level of detail the model tended to hallucinate in its responses at the level of detail. Included were prompts requesting killer tests and asking whether these kinds of tests were already carried out. The fact that the responses were based on misunderstandings of what TGD is, forced to direct attention to the details of the related areas of TGD landscape and this had a very fruitful outcome.

2.2.1 Three kinds of questions related to the interpretation of TGD

The analysis created three kinds of questions related to the interpretation of TGD.

1. The idea [L37, L31] about the phase transition between phases described in terms of Dirac equation in H *resp.* X^4 as a generalization of the notion of the deconfinement phase transition *resp.* hadronization replaces the QCD type description with a stringy description in which the intersection of the space-time surfaces of colliding particles consisting of 2-D string worlds sheets determines the scattering amplitudes. In ZEO, this phase transition would involve two "big" state function reductions reversing the arrow of time and the time.

2. From the beginning it has been clear that color $SU(3)$ is isometry group rather than gauge group and that its subgroup $U(2)$ identifiable as a holonomy group acting on H spinors corresponds to a gauge group. The very definition of CP_2 as coset space states this geometrically.

   (a) Could this mean the reduction of color confinement at the level of spinor quantum numbers to $SU(2)_L$ confinement [L39]? Photons would not be confined, or screened by the pairs of right- and left handed neutrinos screening also the color of leptonic color partial waves [L31].

   (b) Gluons do not appear as couplings of H spinors. Do gluons exist at all and is the identification of classical gluons as projections of Killing vectors wrong? Or do gluons correspond to electroweak gauge potentials in CP_2 spin degrees of freedom and would therefore correspond to electroweak interactions? But is this consistent with the fact that strong interactions are indeed strong?

3. A further stimulus came from the claim of GPT that already the existing data excludes copies of hadron physics labelled by Mersenne primes and their Gaussian variants. Is this really the case and are the earlier indications about bumps [K10, K11] wrong?

   (a) Under what conditions does the phase transition between M_{107} and M_{89} hadron physics occur with a significant rate?

   (b) Is quantum criticality, forcing the Compton scales of ordinary hadrons and dark M_{89} hadrons to be identical, necessary? This is indeed assumed in the model for the bumps as M_{89} mesons reported at LHC. If so, the transition from M_{107} H phase to X^4 phase would occur in the first BSFR and the transition from the X^4 phases to X^4 phase to M_{89} H phase would take place in the second BSFR.

   Just as in TGD inspired biology, the increase of the h_{eff} by factor 512 would require "metabolic" energy feed increasing the quark energies proportional to $h_{eff}f$ by this factor. This energy would come from the collision energy of colliding heavy nuclei. The decay of M_{89} hadrons to M_{107} hadrons would occur spontaneously. This kind of decay at the surfaces of the Sun is proposed to be responsible for the generation of solar wind and solar energy [L24].

   (c) Is the assumption about the labelling of scaled variants of hadron physics by nuclear p-adic length scales too restricted since hadrons (say pions) are labelled also by other p-adic length scales than that of nucleon?

   (d) Could the hierarchy of hadron physics generalize to a hierarchy of standard model physics. These physics would correspond to the hierarchy color representations for quarks and leptons in 1-1 correspondence and labelled by single integer k labelling the color multiplets appearing in the solution spectrum of the Dirac equation in H [L33, L31]. If so, hadrons and leptons for a given value of k would correspond to several p-adic primes?

2.2.2 Progress in the understanding TGD view of the relation between electroweak and strong interactions

TGD view predicts at the fundamental level strong correlations between electroweak, strong interactions and gravitational interactions. But the precise understanding of these correlations has developed rather slowly. The writing of the comments to the GPT prompts was a rather exhaustive process but it was not a waste of time. It led to considerable progress in this respect.

The original proposal motivated by the Kaluza-Klein theory was that gluons classically correspond to the projections of the Killing vectors of $SU(3)$ isometries. The problem was that the Dirac operators in H and in X^4 do not contain couplings to these projections. Only electroweak gauge potentials as identified as induced spinor connection and the induced metric appear.

A radical solution of the problem is suggested by the fact that the electroweak gauge group $U(2)$ as a holonomy group of CP_2 corresponds to a subgroup of $SU(3)$. Could electroweak gauge bosons be gluons! Electroweak interactions are color interactions in spin degrees of CP_2 and strong interactions are color interactions in the orbital degrees of freedom for CP_2 assignable to the color partial waves of H spinors!

In [L27] the possibility that there are no gluon vertices at the fundamental level was discussed so that somehow electroweak couplings also describe strong interactions. The recent general view of interactions allows to make these considerations much more detailed.

1. Also for X^4 Dirac equation one obtains quark color and it would naturally correspond to conformal modes proportional to $(\xi_1, \xi_2, 1)$ possible for the induced Dirac equation and perhaps having interpretation as reduction of color triplet to $U(2)$ doublet plus singlet. The triplet corresponds to different coordinate patches of CP_2 to which the three Z_3 poles can be assigned. Therefore one obtains annihilation to quark pairs in this sense. Conformal invariance could make higher modes gauge degress of freedom.

2. As noticed, a long standing puzzle has been the fact that electroweak $U(2)$ has a holonomy group of CP_2 is the maximal compact subgroup of $SU(3)$. Could one see electroweak interactions as an aspect of color interactions or vice versa? Could one say that there is a symmetry breaking reducing isometry group $SU(3)$ to its subgroup $U(2)$ identifiable as holonomy group and an electroweak gauge group? Could $CP_2 = SU(3)/U(2)$ realize the gauge group nature of U(2) geometrically.

   Could the proposed electroweak confinement by the pairs of left and right-handed neutrinos [L31], screening the weak isospin, correspond to $SU(2)_L \subset SU(3)$ confinement in spin degrees of freedom. There would be no color confinement for photons associated with $U(1)$. The first guess is that a full color confinement takes place for the light states formed from the H spinor modes. A weaker option would be that there is only an $SU(2)$ confinement.

3. If so, the color confinement could take place at two stages and allow us to say that hadrons effectively consist of color triplet quarks.

   In the case of both quarks and leptons, a $\nu_L\nu_R$ pair can be added, which eliminates the weak isospin and gives $SU(2) \subset SU(3)$ confinement in CP_2 spin degrees of freedom. This corresponds to electroweak massivation and symmetry breaking.

   This can neutralize lepton color in orbital degrees of freedom. Also mass squared can vanish when a lepton or $\nu_L\nu_R$ with a negative M^4 mass squared is present. A massless color singlet lepton, massive above Compton length scale is obtained. p-Adic thermodynamics describes the massivation.

   In the case of quarks only a color triplet can be obtained. Masslessness for the triplet is not obtained: by 8-D masslessness, the color Casimir of the triplet gives the M^4 mass squared.

   However, one can build a massless baryon from three color triplet quarks and a meson as a massless quark-antiquark pair. p-Adic thermodynamics produces the mass.

4. Why are strong interactions strong? The annihilation rate to quark pairs by the proposed vertices is sum of three pairs and the rate is 9 times higher than for the annihilation to leptons. The electroweak coupling strength is of order $\alpha_{em} = 1/137$ so that the rate for quark pair production corresponds to $\alpha_s = 9\alpha_{em} \sim .1$. This would give a correct order of magnitude estimate! Since $SU(2)$ is non-Abelian, the coupling constant evolution for $SU(3)$ could have a counterpart as $SU(2)$ counterpart. The electroweak symmetry breaking would characterize this evolution.

5. Old-fashioned hadron physics talked about conserved vector currents (CVC) and partially conserved axial currents (PCAC). These notions emerged from the observations that hadronic reaction rates can be expressed in terms of correlations of electroweak currents. This indeed raises the question whether strong interactions could reduce to electroweak interactions in some sense [K19]. The description of hadron physics in terms of $SO(4) = SU(_L) \times SU(2)_R$ symmetry at low energies conforms with this: $U(2) \subset SU(3)$ would correspond to $U(2) \subset SO(4) \times U(1)$. Strong and weak isospin indeed are one and the same thing!

6. What happens to the scaled up variants of hadron and electroweak physics if strong and electroweak physics fuse to whatever one might call it (unified physics?)? The only way to understand why the range of strong interactions is given by the hadronic length scale is that strong interactions would correspond to electroweak interactions in p-adic length scales,

which correspond to hadrons and possibly also quarks. Weak bosons should correspond to a much longer Compton scale.

Nucleons would correspond to the p-adic length scale $L(107)$ and pions to $M(113)$. The original view of weak bosons was that weak interactions correspond to the scale $L(89)$ corresponding to Mersenne prime. Weak boson mass scales turned out to correspond to $L(91)$

However, the original view is rather attractive and would fit with the view that M_{89} hadron physics fuses with ordinary electroweak physics and several p-adic length scales are involved with a given copy. The copies of this unified physics in turn could correspond to color partial waves for Dirac equation in H.

Electro-weak bosons would be special kinds of mesons in the sense that they are superpositions of both quark and lepton pairs. Photon would be even more special in that $SU(2) \subset SU(3)$ confinement would not apply to it because $U(1)$ is abelian.

The scaling hypothesis, stating that the mass scales of mesons are scaled by a factor 512 in the transition $M_{107} \rightarrow M_{89}$, is probably too strong but gives testable predictions to start with.

1. One key question concerns the M_{107} counterparts of weak bosons. They would correspond to genus $g = 0$ (u and d quarks). A naive scaling of masses by factor 1/512 would give a mass scale near 500 MeV. There is no report about the observation of these bosons.

   For ρ meson the mass scale without QCD hyperfinite splitting induced by color magnetism is around 500 MeV. Are these weak bosons separate from ρ assumed to involve only quark pairs or do they correspond to ρ? For the latter option their decays to leptons should reveal this.

2. What about pseudoscalar π accompanying ρ? Standard model does not predict pseudoscalar electroweak boson. Its counterpart for M_{89} should exist. Evidence is reported for the existence of a pseudoscalar at the intermediate boson mass scale. For $k = 113$, assignable to the Mersenne prime of the nucleus, one obtains the mass estimate 20 MeV. There is strong evidence for X-boson [L2] with mass around 16-17 MeV and I have considered the interpretation as a weak boson. There is also Ytterbium anomaly which could have the same explanation [C7] and Calcium anomaly [C9] related to the difference of atomic energy levels of different isotopes of Ca. These anomalies are discussed from the TGD view point in [L2] [K12].

3. What about M_{107} counterpart of Higgs scalar with mass of 125 GeV? By a naive scaling, it should have mass about 250 MeV. The are many candidates candidates for scalar mesons (see this) but they have masses above the mass 500 MeV of sigma boson whose existence is still not confirmed. σ is a very broad Breit-Wigner type resonance, which does not support interpretation as a scaled down Higgs boson. For $k = 113$ the mass should be around 32 MeV, about twice the mass for X boson.

2.3 Unitarity constraint and the construction of S-matrix in the TGD framework

The recent TGD based view of particle reactions [L31] replaces QCD type approach with its stringy version and allows the construction of S-matrix for arbitrary initial and final states.

1. The construction of S-matrix in elementary particle degrees of freedom reduces to that for fundamental fermions. There are two levels involved. External particles are constructed as bound states of fundamental fermions giving rise to hadrons, leptons, gauge bosons, and gravitons. Number theoretic vision, in particular Galois confinement [L9] ia plays a key role in the construction of the bound states.

   The fundamental fermions correspond to the modes of the Dirac equation in H, being massless in the 8-D sense. If M^4 has hypercomplex Kähler structure the Dirac equation in H allows massless light color singlet states as many-fermion states [L31].

   The analog of the quark phase corresponds to modes of the X^4 Dirac operator for fundamental fermions, which are massless in 4-D sense: color triplets can be understood in terms of CP_2

geometry. The oscillator operators for X^4 modes are expressible in terms of those for H modes [L31].

2. What is highly non-trivial is that the X^4 level is universal unlike the H level labelled representations for color partial waves. Could this explain the finding that lattice QCD was consistent with $g-2$ anomaly of muon but the model based on hadronic data predicted too small an effect. Could the neglected appearance of M_{89} hadrons in the final states [K10] remove the anomaly?

3. The S-matrix is determined by the overlap of these two fermionic state bases and the unitary matrix describing the scattering in the quark phase. Fermion pair creation in the induced classical fields is the basic vertex and reduces to a defect of the standard smooth structure: these defects give rise to an exotic smooth structure [A1, A3, A4].

   In the vertex, fermion current fails to be conserved for the standard smooth structure but is proposed to be conserved for the exotic smooth structure [L13, L10, L27, L31]. The non-vanishing divergence at the defect determines various vertices.

4. Besides the fermionic degrees of freedom, also the geometric degrees of freedom of WCW are included. Holography = holomorphy vision (H-H) [L19, L28, L37, L14] implies that the path integral disappears and there is only a functional integral over 3-surfaces X^3 and the sum over the Bohr orbits for each X^3. Does the role of the functional integral become trivial with respect to unitarity? Locality in WCW suggests that this is the case. Let us assume in the following that this is indeed the case.

Unitarity is a strong constraint in the construction of S-matrix and will be considered in the sequel.

2.3.1 Two T-matrices corresponding to hadronic phase in H and quark phase in X^4

How could the T-matrix for hadronic phase relate to the T-matrix for the quark phase, call it briefly t?

1. t would be related to scattering in the string phase, where the quarks would be free or rather at the boundary lines of string world sheets at light-like partonic orbits. The phase would consist only of conformally massless quarks and leptons at the fermionic lines. H-H would determine the space-time surfaces X^4 and fermionic modes.

2. We can start from unitarity. In the hadron phase, the scattering amplitude satisfies the condition$T - T^\dagger = TT^\dagger$. Unitarity would also hold for t in the quark phase. In the forward direction, a cut for T in the forward direction essentially gives the total cross section.

3. The scattering would correspond to two "big" state function reductions (BSFRs) changing the arrow of time [L6, L15]. T would be between the hadron phases and $T^\dagger$ between their time reversals. The same applies to t.

   This suggests a concrete interpretation of unitarity. T and $T^\dagger$ would correspond to opposite time directions. Analogously, t and $t^\dagger$ would be associated with a sequence of SSFRs in opposite time directions, increasing the size of the CD as a correlate for the geometric time. This would give a concrete geometric meaning for the unitary conditions.

4. T would decompose into a product of three operators. The first one would be the operator O, which would project from the hadron phase to the quark phase. It could, and actually should, be a 1-1 map. The second operator would be t or $t^\dagger$, which would describe the scattering operator in the quark phase. The third would be the inverse operation of O. It should be possible to identify it uniquely, but if O is not 1-1, then there might be problems.

5. H-H gives strong conditions. t would correspond to a sequence of SSFRs and classical non-determinism would determine t. The creation of quark pairs is the basic process created by t, and here exotic smooth structures would come into play [L13, L10].

2.3.2 Could the unitarity for T reduce to unitarity for t?

1. O projects the hadronic state into a state consisting of quarks and the latter evolves according to t. After that, the quark state would to a hadronic state and the inverse of O would be included. The reduction $T \rightarrow t$ from the hadronic level to the quark level takes place if an inverse of O exists.

2. If quark states can be mapped in 1-1 way to hadronic states, then the classical non-determinism, which can be interpreted as a cognitive non-determinism, would completely determine t. Everything would be discrete and extremely simple at the quark level. Note however that quark pair production occurs and the defect of the standard smooth structure as a classical correlate.

   The transition involves the usual quantum physical non-determinism, which naturally to O and its inverse. O would be completely determined by the overlap of the spinor modes of H and X^4 determined by H-H.

2.3.3 Can the matrix O be invertible?

Can O define an isometry between two different state spaces? The analog of a projection from the hadron phase to the quark phase is in question, and it need not be an isometry. The analog of projection, or rather, the map, of O from the hadron phase to the quark phase is well-defined. Can O have a unique inverse? Light-likeness in H and light-likeness in X^4 are very different notions physically: is a 1-1 correspondence between hadronic and quark states possible?

1. Could the additional degrees of freedom in the quark phase come from the fact that X^4 is not closed like CP_2 and CD is finite? Conformal modes would diverge in H but not in X^4 and increase the number of the fermion modes. The argument does not seem convincing to me.

2. Classical non-determinism [L23] brings in additional degrees of freedom identified as cognitive degrees of freedom. Could this make isometry possible?

3. Could additional degrees of freedom in the quark phase emerge from an improved measurement resolution needed to "see" the quarks. This would correspond to a larger extension to rationals and that in turn to cognitive non-determinism so that this option is equivalent with the third option.

2.3.4 About the role of hyperfinite factors (HFFs)?

1. HFF [K20, K7] [L20] is a fractal and contains hierarchies of subalgebras isomorphic with HFF itself. The number-theoretic vision assigns such hierarchies as hierarchies of algebraic extensions of rationals. Also measurement accuracy can be defined in terms of algebraic complexity.

2. The concept of inclusion is central. A subfactor corresponds to a subalgebra of the factor. Inclusion is not a 1-1 correspondence nor isometry. For a factor, the trace of the unitary operator is $Tr(Id) = 1$ and for a sub-factor, the trace of the projector to it is $Tr(P) = q \leq 1$. q is quantized. There is a close connection with quantum groups and related concepts. The concept of HFF is particularly natural for fermions, so that it nicely fits into TGD.

3. Does the quark phase correspond to a subfactor of the hadron phase? Could classical non-determinism increase the value of q to unity and make the correspondence an isometric embedding of the quark operator algebra to hadronic operator algebra?

2.4 About the structure of the vertices

It is now intuitively clear that the vertices at the fundamental level should be just the standard model vertices assignable to the 3-D singularities of the divergence of the fermionic current. Also the idea that the vertices should have an interpretation as defects of standard smooth structures to which exotic smooth structure [A3, A4, A1] can be assigned [L22, L10, L27]. The difficult challenge (to me at least) is to deduce the vertices in a convincing way. The option discussed below seems to be the most promising of the options considered hitherto.

2.4.1 Are the vertices due to the non-conservation of fermion current associated with the induced/modified Dirac action

One can start from the standard model view of vertices as an intuitive guide line.

1. The singularities should give the emission vertices for Higgs and electroweak gauge bosons. What is new is that electroweak gauge bosons have an interpretation as gluons with the weak gauge group identified as the holonomy group $U(2)$ identifiable as a subgroup of color group $SU(3)$. Strong interactions correspond to the isometries of $SU(3)$ and electroweak interactions to the holonomies assignable to the CP_2 spinor degrees of freedom. Generalized Higgs corresponds to the trace of the second fundamental form having a 3-D singularity at the vertex. This means that the classical action has no role as far as vertices are considered.

2. The interaction vertices emerge from the induced/modified Dirac action. By the modified Dirac equation, this action vanishes almost everywhere. The Dirac action reduces to a divergence of the fermion current and this suggests that at the singularity this divergence is non-vanishing. This conforms with the view that a fermion pair is created and fermion line terms backwards in time. At the 3-D singularity the divergence of the fermion current should have a delta function divergence making possible non-vanishing various vertices.

3. The vertex for the generalized Higgs is not a problem. The trace of the quantity $D_\mu(\Gamma^\mu\sqrt{g_4})$ is proportional to the trace of the seocnd fundamental form and gives 3-D delta function for the vertex of the annihilation of Higgs to fermion-antifermion pair.

4. How to obtain electroweak vertices and the possible vertex related to the M^4 Kähler gauge potential? The electroweak vertices should come from a 3-D delta function singularity X^3 of the Dirac action density $\overline{\Psi}(-\overleftarrow{D_\mu}\Gamma^\mu - \Gamma^\mu D_\mu)\Psi\sqrt{g}$.

   The problem is that the components of the induced spinor connection A have only a step function like discontinuity rather than the desired delta function singularity. The desired singularity should be equal to the difference $A_+ - A_-$ of the gauge potentials at the two sides of the singularity, which is invariant under gauge transformations if their action is the same at the two sides. Vertex would be defined by this difference rather than vector potential as in perturbative gauge theories.

5. This can be achieved if the spinor fields have a discontinuity at X^3, which gives rise to the difference $A_+ - A_-$ under the action of derivatives to the spinor field at X^3. This is achieved if the gauge potentials A_+ and A_- are related by a gauge transformation g in the holonomy group. This gives $A_+ = A_- + dgg^{-1}$ giving $dg = (A_+ - A_-)g$. The spinor fields are discontinuous at the singularity and related by $\Psi_+ = g\Psi_-$. The derivative $d\Psi_+$ is given by $d\Psi_+ = d(g\Psi_-) = dg\Psi_- + gd\Psi_- = (A_+ - A_-)g\Psi_- + gd\Psi_-$. The difference of gauge potentials at the singularity gives rise to the desired vertex.

6. For this option, the vertices are universal and do not depend on classical action for the induced Dirac equation. Also for the modified Dirac equation the electroweak vertices are determined by a gauge transformation in the holonomy group of CP_2. The conservation of the isometry currents for the classical action implies that the Higgs vertex as the divergence of the induced/modified Gamma matrices are expressible in terms of current assignable to the remaining parts of the action. If the classical action is a mere volume action, the conservation of classical isometry currents does not allow singularities. Therefore Kähler action plus volume term strongly suggested by the twistor lift is the minimal option.

2.4.2 The relation to the exotic smooth structures

The vertices should be non-trivial for the 3-D singularities at which the minimal surface property of the space-time surface fails and which corresponds to the defects for the standard smooth structure, which transform it to exotic smooth structure [A3, A4, A1]. What does this really mean, is far from clear. I have discussed this problem already earlier [L22, L10, L27] but I am not satisfied with the view.

The edge of the fermion line at the singularity means the breaking of standard smooth structure at which the light-like hypercomplex coordinate changes from u to its hypercomplex conjugate v. The derivatives of the embedding space coordinates as functions of u *resp.* v at the singularity are infinite for the standard smooth structure. Also the induced Dirac spinors are discontinuous and related by a gauge transformation at the two sides of the singularity if the above argument is correct.

For the exotic smooth structure, the derivatives are continuous at the singularity. Also the vertices should remain the same in the exotic smooth structure. The only reasonable identification of the vertices is as regions at which the exotic smooth structure fails to reduce to the standard smooth structure. Could one introduce a 3-D term to the Dirac action additional term localized to the singular surfaces of the standard smooth structure to guarantee that the non-vanishing divergence of the ordinary Dirac action is compensated by this additional term giving rise to the standard model vertices for the Dirac action.

I have proposed the assignment of Chern-Simons-Kähler action and its fermionic counterpart to the 3-D light-like partonic orbits and a similar term can be considered also now. The modified Dirac action for the Kähler Chern-Simons term would contain the standard model couplings to spinors.

2.4.3 Analog with Higgs mechanism and 3-D singular surfaces as analogs of soap bubbles

The vertices for the fermion pair creation are located 3-D singular surfaces X^3 at which the conformal invariance fails. Can one say anything interesting about these 3-surfaces or even find a possible analogy with the existing physics? The idea that the trace of the second fundamental form which becomes singular at X^3 relates closely to Higgs has been around from the beginning of TGD. In the following I want to show that this idea has finally found a precise form.

1. The trace of the 8-D second fundamental form defines a generalized local acceleration orthogonal to the space-time surface X^4, which vanishes almost everywhere by the minimal surface property. It is non-vanishing only at the 3-D singularities X^3 representing edges of X^4.

   The vertices for fermion pair creation as edges of fermion lines are assigned to intersections of string world sheets with X^3 in the intersection of intersecting space-time surfaces with the same Hamilton-Jacobi structure.

2. The second fundamental form is analogous to generalized Higgs, call it H, with the CP_2 part being group theoretically like the ordinary Higgs field and indeed causing a violation of the conservation of M^4 chirality. The M^4 part is identifiable as ordinary local acceleration.

   The generalized acceleration has the dimension of inverse length, that is the dimension of mass divided by Planck constant. Higgs vacuum expectation corresponds to the fermion mass in the standard model. Is this true also in TGD?

3. By both Dirac equation in H and Dirac equation with M^4 Kähler form for CD the fermions are massless in 8-D sense. If the additivity of M^4 mass squared, identified as a conformal weight, is assumed, all many-fermion states have a vanishing mass squared in 8-D sense so that the total M^4 mass squared equals to CP_2 mass squared proportional to color Casimir. It vanishes for color singlets but has a CP_2 mass scale as a natural unit for colored states.

4. If M^4- and CP_2 parts of the generalized Higgs have magnitude equal to the mass squared of the particle, quantum-classical correspondence is realized. p-Adic thermodynamics would predict M^4 mass squared [L11].

   At X^3, the condition $a_{M^4} = m/h_{eff}$ for the M^4 acceleration, where m the mass of the particle, would be satisfied. Conformal invariance would fail X^3 but the 8-D masslessness would remain true. Local mass value depends on the point of X^3 unless the magnitudes of a_{M^4} and a_{CP_2} are constant. The direction of 8-D acceleration is orthogonal to X^4 and also X^3.

5. What could be the physical interpretation for the possible constant magnitude of M^4 and CP_2 accelerations? Isometrically embedded 3-sphere in E^4 represents a basic example of this kind of surface. Also a soap bubble is an example of a surface with constant value of local acceleration. The surface tension corresponds to the local acceleration and is proportional to the pressure difference. This suggests that the 3-D singularities are analogous to the surfaces of 3-D soap bubbles.

2.5 A brief summary of the TGD based view of standard model interactions

The general view of standard model interactions provided by TGD differs dramatically from the QCD view and also from the Standard Model picture and one might hope that the findings could provide convincing support for the TGD view.

1. Space-time at the fundamental level consists of 4-surfaces X^4 in $H = M^4 \times CP_2$ obeying holography= holomorphy principle (H-H), which reduces the field equations to local algebraic conditions. Theory is exactly solvable.

2. Color is not a spin-like quantum number as in QCD but analogous to orbital angular momentum in CP_2 and characterizes both leptons and quarks. Arbitrarily high color partial waves are possible.

3. All particles are bound states of fundamental fermions. Colored fermions as modes of Dirac equation in H have mass of order CP_2 mass ($\sim 10^{-4} M_{Pl}$) but color singlet many quark states and leptons are light and correspond to the particles observed in the laboratory.

4. By H-H, the Dirac equation in X^4 for the induced spinors in induced spinor structure allows massless quarks and leptons. This phase is the analog of the quark-gluon phase: gluons are not however present, just fundamental fermions. The interaction region for the collision of particles corresponding to 4-D space-time surfaces with the same generalized complex structure is the intersection of the space-time surfaces consisting of string world sheets so that a stringy description of interactions emerges. TGD generalizes the QCD type description of scattering to all interactions.

5. Color and electroweak interactions are very closely related since CP_2 isometries correspond to SU(3) and holonomies of CP_2 correspond to U(2) identifiable as a subgroup of SU(3). One can say that electroweak interactions are color interactions in electroweak spin degrees of freedom and color partial waves are analogous to angular momentum degrees of freedom.

3 Could standard model have anomalies after all?

I heard very interesting news from LHC (see this). The title of the post at Restoration Monk is "CERN Detects First-Ever Quantum Gravity Clues from Proton Collisions".

The official narrative has been that the standard model works too well so that there are no signals serving as guide lines in attempts to extend the standard model. I have had difficulties with swallowing this story since this claim has been in conflict with what I have learned during years.

However, I learned now that over the past 10 years, deviations from both QCD and Standard Model physics, related to the supposed phase transition to quark gluon plasma, have been observed. The reports of these findings are scattered in literature. The article about these findings has been submitted for publication in The European Physical Journal.

The Google summary, which I obtained using the prompt "anomalous energy distributions in quark-gluon plasma events that deviate from predictions of both the Standard Model and supersymmetry" gives the following general data bits.

1. The LHC experiments have observed unusual patterns in the energy distribution of particles within the quark-gluon plasma, a state of matter believed to have existed shortly after the Big Bang.

2. There are deviations from Standard Model and Supersymmetry: These energy distribution patterns don't match predictions from either the Standard Model, which describes fundamental particles and forces, or supersymmetry, a theoretical framework extending the Standard Model.

The proposal mentioned in the popular article is that the observed anomalous effects could relate to quantum gravity. This would require that Newton's constant is renormalized to a very large value and looks to me unrealistic.

3.1 The general TGD based view of standard model interactions

The general view of standard model interactions provided by TGD differs dramatically from the QCD view and also from the Standard Model picture and one might hope that the findings could provide convincing support for the TGD view.

1. Space-time at the fundamental level consists of 4-surfaces X^4 in $H = M^4 \times CP_2$ obeying holography= holomorphy principle (H-H), which reduces the field equations to local algebraic conditions. Theory is exactly solvable.

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3.2 TGD inspired guess for the list of deviations

The above summary is very general and does not reveal any details. I have however worked with the problem of understanding the difference between TGD and standard model view for decades and it is relatively easy to fill in the details.

As a matter of fact, the deviations have been observed in what has been interpreted as a transition to quark plasma phase. They are familiar to me and they have emerged during a time period of about 20 years. I have discussed a large number of potential anomalies of the standard model from the TGD point of view [K10], in particular in the section "Still about quark gluon plasma and M_{89} physics". TGD predicts a hierarchy of standard model physics and the ordinary M_{107} hadron physics and M_{89} hadron physics are only two examples of them. These standard model physics correspond to the hierarchy of color partial waves for quarks and leptons [L33, L31, L35].

The first deviations that I have commented on were reported by ALICE collaboration.

1. RHIC had already observed around 2005 in heavy ion collisions that the phase assumed to be quark gluon plasma at quantum criticality for the formation of quark gluon plasma behaved almost like a perfect fluid [C6]. This was surprising. Around 2010 the same observation was made by LHC in proton-proton collisions.

2. The popular article "ALICE collaboration measures the size of the fireball in heavy-ion collisions" [C10] (see this) appeared in CERN Courier 2111. The fireball served as a meson source and had elongated shape in the direction of the collision axes rather than being a spherical object: this suggests that string-like or meson-like object was in question. TGD interpretation was as a meson of M_{89} hadron physics.

3. The second popular article (see this) in CERN COURIER from year 2113 talks about the observation of Alice suggesting an double ridge structure consisting of two peaks in momentum space corresponding to opposite longitudinal momenta [C2]. Also this suggests a string-like or meson-like structure.

   The proposed TGD based interpretation was that the phase transition is not from hadron phase to quark gluon plasma but from ordinary M_{107} hadrons to M_{89} hadrons. In TGD, hadrons correspond to stringy objects made from monopole flux tubes and the stringy object could be a meson of M_{89} hadron physics for which the proton mass is 512 the mass of the ordinary proton. The hadrons of this physics would be dark in the sense that they would have $h_{eff}/h = 512$ so that the size of the dark proton would be that of the ordinary proton. This would make possible geometric resonance. Large value of h_{eff}/h would predict small dissipation and this conforms with the ideal fluid behavior. Hydrodynamics boils down to conservation laws and the classical field equations of TGD are indeed conservation laws for isometry charges solved by holography= holomorphy hypothesis.

4. Also bumps were detected that were first interpreted in the framework of then fashionable SUSY. This interpretation failed and the bumps were forgotten. TGD suggested their interpretation as M_{89} mesons and the estimate for their masses using naive scaling by a factor 512 gave encouraging results:see the sections "Scaled Variants of quarks and leptons" and "Scaled variants of hadron physics and electroweak physics" of [K10].

Some time ago I learned from an anomaly related to weak isospin [L39], discussed from the TGD point of view [L25, L26] in [L39]. There are excellent reasons to expect that this anomaly belongs to the list of findings. The production rate for strange mesons is higher than for their charmed counterparts. This implies charge asymmetry, which is very difficult to understand in QCD since electroweak symmetries and color symmetry are completely uncorrelated.

In the TGD framework, leptons and quarks move in color partial waves and the color partial waves are different for different weak isospin values so that the charge asymmetry emerges at the fundamental level for color interactions.

One particular proposed explanation for the findings made during 10 years in terms of gravitons might have some empirical justification. In the TGD framework, a natural counterpart of graviton would be emission of spin=2 meson of M_{89} hadron physics.

3.3 How ordinary nuclei can be produced in very high energy collisions of protons?

I learned about a possible solution of a long-standing anomaly related to the proton collisions at very high energies studied at LHC using the ALICE detector. There is a popular article in CERN Courier (see this) telling about the findings published in Nature [C4].

1. The production of deuterons and antideuterons was studied. A long standing mystery has been why also light nuclei are produced so abundantly. At the huge energies involved the temperature is of order pion mass scale $\sim$ 100 MeV and is so high so that the nuclei have quite too low binding energy to survive and only nucleons should be produced.

2. The researchers found evidence that the about 90 per cent of the deuterons were produced by nuclear fusion from the particles emerging from the collision with one of the particles emerging from a decay of a massive short-lived particle, so called Δ resonance, which consist of 3 quarks just like nucleons. Δ decays in a time of order 10^{-24} seconds to nucleon and pion. Note that proton Compton time is about 33 times longer than this time.

3. The studies support the view that decay occurs in the periphery, at sufficient distance from the collision point, where the temperature is lower and the fusion can produce stable deuteron nuclei. The article also mentions that the findings provide support for a model of cosmic ray interactions as cascades.

   The proposal is that the d (anti-d) formation is made possible by pion catalysis. The reaction would be $\pi+p+n \rightarrow \pi+d$ and the final state pion would carry away the 4-momentum. The pion would be produced in the decay of Δ.

These findings are very interesting from the point of view of TGD.

1. TGD predicts the symmetries of the standard model but since QCD color does not correspond in TGD spin-like quantum number but to partial waves in CP_2, both quarks and leptons move in color partial waves and each color multiplet gives rise to a scaled version of the standard model physics. An infinite hierarchy of standard model physics is predicted. Ordinary hadron physics would correspond to Mersenne prime $M_{107} = 2^{107} - 1$ and the next one, for which there is evidence from anomalies at LHC, to Mersenne prime M_{89} with mass scale, which is 512 times higher than for ordinary hadrons (nuclei). For instance, the pion of M_{89} hadron physics would have mass scale $512 \times 140 MeV \simeq 70$ GeV.

2. The recent solar model is plagued by anomalies. In the TGD based view of the Sun, solar wind and radiation are produced at the surface layer of the Sun in the transformation of M_{89} hadrons to ordinary haxrons.

   M_{89} hadrons would decay to ordinary M_{89} hadrons by a process that I call p-adic cooling. The p-adic mass scales would be reduced by powers of 2 (or $\sqrt{2}$ and for the first option (107-89)/2=9 steps would be involved [L24]. One of the first applications of the p-adic physics was the proposal that p-adic cooling could be involved with very high energy cosmic ray events like Centauros [K10, K11].

3. The emerging ordinary nuclei produced in the p-adic cooling could fuse to heavier ones by what I call dark fusion, which provides a TGD based model for the "cold fusion" to heavier nuclei. Less plausibly, they could be produced in the p-adic cooling directly. These heavier nuclei gradually fall downwards in the gravitational field of the Sun so that the usual layered structure of nuclei is near the surface of the Sun rather than in the core of the Sun.

4. Quite recently, a direct support from this layered structure emerged from very weird findings related to a Supernova explosion. One cannot even exclude the possibility that the same process could have occurred even in the formation of planets as a surface layer of the Sun exploded [L34, L21, L16, L17].

Consider now the very energetic proton and heavy ion collisions from the TGD perspective.

1. The TGD view of generalizes the QCD view of hadron collisions [L35]. The interaction region contains the TGD analog of quark gluon plasma in which fermions move as massless particles and obey at the spae-time surfaces induced Dirac equation. In final hadron states the Dirac equation in $H = M^4 \times CP_2$ is satisfied. These equations are consistent with each other.

   The counterpart of quark gluon plasma corresponds in QCD to the fragmentation of initial state hadrons to quarks but not gluons as elementary particles. In TGD, gluons as all elementary bosons would only exist as fermion-antifermion pairs. Hadronization correspond to the fusion of quarks and antiquarks to form massive hadrons. This picture applies to all particle reactions, also those involving leptons. In fact, weak interactions and color interactions can be seen as aspects of color interactions.

2. In the TGD Unverse,M_{89} hadrons could be created in very high energy nuclear and proton collisions in a TGD counterpart of the transition interpreted as a formation of quark gluon plasma. M_{89} hadrons would have effective Planck constant $h_{eff}/h = 512$ and mass scale 512 times higher than for ordinary M_{107} hadrons so that the Compton scales for M_{89} and M_{107} hadrons would be the same. This would correspond to quantum criticality for $M_{107} \rightarrow M_{89}$ phase transition as the TGD counterpart for the QCD transition to quark gluon plasma.

3. The hadronization would lead to the formation of M_{89} hadrons rather than only M_{107} hadrons, say M_{89} pions, whose age would be the same as for ordinary hadrons if it scales like $(h_{eff}/h) \times m_{107}/m_{89} = 1$.

4. M_{89} pions would decay by a p-adic cooling to ordinary nucleons. Dark fusion (or ordinary fusion, which in the TGD framework could actually reduce to dark fusion) at a sufficiently large distance from the collision point could produce nuclei.

5. What would be the value of h_{eff}/h, if the dark fusion occurs. If it is equal to 512, the Compton lengths of ordinary nuclei would be scaled up by factor 512 and would be of the order of electron Compton length. Could this allow us to understand why the fusion occurs in the periphery with a high probability?

   At the temperature $T \sim m(\pi_{107})$ the thermal energy $E_{th} = T - m(\pi_{89})$ of π_{89} pions is $E - m \simeq (\pi_{89})[1/(1-\beta_{th}^2)^{1/2} - 1]$ giving the estimate $\beta_{th} \sim m(\pi_{107})/m(\pi_{89})^{1/2} \simeq 2^{-9/2}$. Could the slow thermal velocity imply that also the decay products of π_{89} move slowly. Could this increase the rate for the cold fusion proportional to the inverse of the relative velocity?

   Note that if Δ has $h_{eff}/h = 512$, its lifetime is scaled up by this factor and is by a factor ~ 15 longer than the proton Compton time. What if also the produced pion and the nucleons involved have as $h_{eff}/h = 512$? Could this increase the cross section for the pion catalyzed fusion to deuteron.

6. In the TGD based model for the "cold fusion" [L29], the value of h_{eff}/h would be of the same order of magnitude since the scale up Compton length of proton would be of the same order of magnitude as electron Compton length. The Δ resonance could be generated at the last step of the p-adic cooling. The question boils down to whether also the ordinary hadrons, rather than only M_{89} hadrons, can have a large value of h_{eff}/h and whether the effective scaling of the quantum coherence length in the transversal degrees of freedom can make possible the creation of light nuclei by the TGD dark fusion as the counterpart of "cold fusion". This question is very relevant also for the TGD based solar model.

3.4 Challenging the standard view of neutrinos

Marko Manninen sent me a highly interesting link to the work of Prof. Anca Tureanu (see this), who challenges the prevailing standard physics view of neutrinos (see this).

Also in my opinion, the theoretical physics picture of neutrinos is wrong.

1. Both neutrinos and quarks mix: we talk about CKM mixing. Neutrinos are no different from d-quarks in this respect. The mixing model for neutrinos coming from the Sun is in serious trouble. It assumes resonant mixing inside Sun and this is a completely ad hoc feature. This, along with many other anomalies, calls into question the entire view of the Sun's nuclear physics, on which the repeated failed attempts to build hot fusion reactors are based [L24]. Strictly speaking, both U and D quarks as well as charged leptons and neutrinos mix: the difference in mixing corresponds to CKM mixing. What mixing is, is a complete mystery in the Standard Model.

   In TGD, mixing is reduced to topological mixing between different topologies of 2-dimensional parton surfaces [K3]. A sphere, a torus, and a sphere with 2 handles define the relevant parton topologies. For example, a torus collapses into a sphere in a mixing and a quantum state is a superposition of different topologies. TGD explains why there are 3 generations (why there couldn't be 3 handles, for example) and p-adic thermodynamics correctly predicts masses for different generations. Higher generations would be many particle systems of handles with continuum mass spectrum.

2. One problem is whether neutrinos are massless or not. There is strong evidence for their massivation and in TGD the masses can be predicted by p-adic thermodynamics [K9, K3] [L11, L30, L40].

   However, a right-handed neutrino has one exactly massless mode [L33, L31], which is color singlet but also an infinite number of colored modes like other fermions which are associated with color singlet physical states. Color confinement therefore applies also to leptons. The new view of color leads to the prediction of a hierarchy of copies of Standard Model physics [L35]. There is already support for this prediction.

The problem with masses is more general: also quarks are effectively massless in quark-gluon plasma but massive in initial and final states. The concept of quark-gluon plasma seems to be a much more general notion than believed. The proper understanding of this notion could allow us to get out from the confines of QCD and the standard model. TGD indeed leads to a new view of what happens in particle reactions and generalizes the quark-gluon-plasma state to all particles [L38].

3. There is also the problem of the inert neutrino. It begins to be clear that there is no such thing as an inert neutrino. But the observations require something new to explain the observations. The observations are explained if neutrinos can be in a "dark" $h_{eff} \geq h$ states [L8]. Similar darkstate for protons, playhing a key role in TGD based quantum biology, explains the anomalous finding that the life-tme of a neutron depends on the way it is measured [L4].

I looked at Anca Tureanu's article (see this). In the article, Tureanu claims that there is a logical contradiction in neutrino physics.

1. The reaction rates are calculated by considering incoming and outgoing neutrinos as mass eigenstates. In contrast, in neutrino mixing observed in laboratory experiments, quantum coherent superpositions of neutrino generations of different masses are assumed in the model of mixing. The model can be tested in laboratory experiments.

   The mixing model is applied to the solar neutrinos inside the Sun. One has to make a very ad hoc assumption about a resonance arising in the interaction with the environment (low energy neutrinos interact extremely weakly). Quarks are also mixed in incoming and outgoing states, but they are assumed to be eigenstates of mass. Note that we cannot study the possible dynamic mixing of quarks in the laboratory.

2. Can neutrino states with different masses be in quantum superposition? Or do they have to be massless for this to be possible? In what sense would they be massive? Tureanu proposes that neutrinos are massless but that in some sense also massive.

   The proposal is that the phenomenon is analogous to birefringence, which occurs in an insulator, where the dielectric constant for photons coming in perpendicular directions is different. The velocity of propagation is light speed $c \leq c$ as in the case of a massive particle. The different polarizations of the incoming light are refracted differently because the speeds of light are different. The light beam splits into two beams travelling in different directions. In birefringence, the polarizations move at speeds $v_1 \leq c$ and $v_2 \leq c$. In this sense there is a superposition of photons with different masses.

   What about neutrinos? Instead of two polarizations for neutrinos, there would be 3 different generations moving at different speeds $v_1, v_2, v_3 \leq c$ in a substance that would be analogous to a birefringent substance. This would give them an effective mass. The polarization direction would be replaced by mass. Now there would be no refraction.

How does this relate to TGD?

1. One of the fundamental differences between TGD and GRT are warped 4-surfaces, which are gravitationally and electroweak vacuums but for which the speed of light c is less than c [K22]. The surfaces are analogous to a thin metal plate that is unstable and vibrates, but does not stretch. This means that the light signals along the surface propagate more slowly because the distance between two points is longer.

2. The simplest example of a warped (and therefore flat) space-time surface is obtained by considering a geodesic circle of CP_2 with radius R and angle coordinate Φ. Denote the Minkowski coordinates of M^4 with m^k and the coordinates of space-time surface X^4 by x^α. The 4-surface is defined as a map $X^4 \rightarrow H = M^4 \times CP_2$ given by $(m^k = \delta^k_\alpha x^\alpha, \Phi = \omega x^0)$, where $k = (\omega, 0, 0, 0)$ is time-like vector. The time-like geodesic of M^4 is mapped to a light-like

geodesic of H. The induced metric is $g_\beta \leftrightarrow (1-R^2\omega^2,-1,-1,-1) \equiv ((c_{/c})^2,-1,-1,-1)$. The light velocity is reduced to $c_{/c=\sqrt{g_{tt}}=\sqrt{1-R^2\omega^2}}$. Note that Lorentz transformations produce additional solutions.

The square of M^4 projection of the 4-velocity dmk/dx^0 equals constant $R^2\omega^2$ just as for a massive particle. Therefore warping has two interpretations. Particles are massless in the induced metric of X^4. They are also massless in the metric of H but massive in the metric of M^4.

This generalizes from the level of flat space-time surfaces to the level of Hamilton-Jacobi structures [L14] and does not need to be limited to flat 4-surfaces.

3. There is actually empirical evidence for the warping from neutrino physics. In the case of SN1987A, the neutrinos arrived in two pulses [K1]. I explained this using different warpings of the space-time sheets along which the neutrinos of pulses arrived. Quite recently, it turned out that warping also provides an elegant model for the Allais effect.

4. Ordinary refraction for electromagnetic waves would occur at the interface of two regions with different c. The phenomenon would be completely general and also occur for fermions (in TGD all particles are composed of fundamental fermions). In particular, massless neutrinos.

   In birefringence, different spin directions would be associated with different c values. Could there be substances, where this would happen for fermions as well. Polarizations would correspond to different helicities (M^4 chiralities) correlating with CP_2 chirality by fermion number conservation.

5. It however seems that in some sense neutrinos are massless and in some sense massive. This is a paradox. In TGD this is true for all particles. Initial and final many particle states are 8-D and particle states in interaction volume are 4-D.

   In the interaction volume the system is a 4-D surface and fermions fulfill the analogy of the 4-D massless Dirac equation. From the initial and final states of scattering fermions fulfill the 8-D Dirac equation and are massless in the 8-D sense but massive in the 4-D sense. This would generalize the notions of hadron phase and quark-gluon plasma phase so that it applies to all particles. Hadrons appear in the 8-D initial and final states and quarks appear in the 4-D interacting states. Color confinement occurs for both quarks and leptons and there is an infinite hierarchy of standard model physics since there is infinite hierarchy of color partial waves in CP_2 for both quarks and leptons.

6. The 4-surfaces associated with fermions would be massless but characterized by the reduced speed of light c. Like photons, they would have an effective mass in the interaction volume. Warping gives a precise formulation of the intuition that fermions, in particular neutrinos, are massless in both H and X^4 but massive in M^4. Different neutrinos as 4-surfaces would correspond to different values of c: this would be the counterpart for M^4 massivation. p-Adic thermodynamics applied to superconformal representations at the level of H [K9, K3] [L11, L30, L40] allows us to calculate the M^4 masses as thermodynamic expectation values.

4 The findings of RHIC about quark gluon plasma from the TGD point of view

I encountered a highly interesting popular article in which the work at RHIC relating to a phase transition to quark gluon plasma (QGP) dominated phase was discussed. The title of the popular article (see this) is "Clear Sign that QGP Production 'Turns Off' at Low Energy". The title of the article (see this) published in Phys Rev Letters [L38] "Beam Energy Dependence of Fifth- and Sixth-Order Net-Proton Number Fluctuations in Au+Au Collisions at RHIC" is so technical that it does not tell much to a layman. However, since fluctuations characterize criticality, one can guess that criticality is studied.

1. Collisions of Gold ions have been studied at RHIC. The cm energy per nucleon has varied from 3 GeV to 200 GeV. At LHC the upper limit for energies is considerably higher, about 5

TeV and therefore 25 times higher. The research has shown that the behavior of the quark gluon plasma differs rather dramatically from the expectations.

2. What is the critical temperature for the transitions to quark gluon plasma? This has been one of the key questions. No definite answer has been found although $\sqrt{s_{NN}} = 19.6$ GeV is considered as a candidate for 19.6 GeV for the critical collision energy per nucleon. However, a bumpy structure is observed also below this energy down to 3 GeV. Therefore the existence of a single critical temperature can be challenged. It is also clear that a first order phase transition involving single discontinuities of various thermodynamic observables is not in question.

   A more technical way to say this is as follows. What is studied are higher order cumulants for proton number fluctuations around average. At quantum criticality they are expected to be large. At higher collision energies they deviate from those predicted by a first order phase transition. At low collision energies the "off" signal shows up as a sign change—from negative to positive—in data that describe "higher order" characteristics of the distribution of protons produced in these collisions. To sum up, a higher order statistical analysis of protons emitted from a wide range of gold-gold collision energies shows clear absence of a quark-gluon plasma (QGP) at the lowest collision energy.

Here is the abstract of the article "Beam Energy Dependence of Fifth- and Sixth-Order Net-Proton Number Fluctuations in Au+Au Collisions at RHIC" [L38] summarizing the findings at RHIC.

We report the beam energy and collision centrality dependence of fifth and sixth order cumulants (C_5, C_6) and factorial cumulants (κ_5, κ_6) of net-proton and proton number distributions, from center-of-mass energy ($\sqrt{s_{NN}}$) 3 GeV to 200 GeV Au+Au collisions at RHIC. Cumulant ratios of net-proton (taken as proxy for net-baryon) distributions generally follow the hierarchy expected from QCD thermodynamics, except for the case of collisions at 3 GeV. The measured values of C_6/C_2 for 0%–40% centrality collisions show progressively negative trends with decreasing energy, while it is positive for the lowest energy studied. These observed negative signs are consistent with QCD calculations (for baryon chemical potential, $\mu_B leq 110 MeV$) which contains the crossover transition range. In addition, for energies above 7.7 GeV, the measured proton , within uncertainties, does not support the two-component (Poisson + binomial) shape of proton number distributions that would be expected from a first-order phase transition. Taken in combination, the hyper order proton number fluctuations suggest that the structure of QCD matter at high baryon density, $\mu_B \sim 750 MeV$ at $\sqrt{s_{NN}}$=3GeV is starkly different from those at vanishing $\mu_B \sim 24 MeV$ at $\sqrt{s_{NN}}$ =200GeV and higher collision energies.

4.1 A brief summary of the findings at RHIC

Consider first a brief summary of the unexpected RHIC findings (see this) concerning the creation of what is thought to be QGP. The study revealed many surprises.

1. Jet quenching means that jets predicted by QCD lose energy much faster than expected. This would be due to the strong interactions with quark gluon plasma implying dissipation. In QCD, this interaction is modelled in terms of collisions of quarks with the quark gluon plasma formed by quarks and gluons.

2. The almost ideal perfect fluid behavior was totally unexpected. This hydrodynamic flow is known as elliptic flow. A further surprise was that heavy quarks also participate in the elliptic flow. This is like boulders flowing in a river.

3. Also light ions create the quark-gluon plasma. QGP, or whatever it is, is created even in the collisions of photons and heavy ions.

4. The basic questions concern the critical temperature and critical collision energy per nucleon at which the transition to QGP occurs. There is no consensus but the proposal is that 19.6 GeV collision energy could be a critical point. There is however a bumpy structure also below this critical point.

4.1.1 TGD view briefly

What can be said about these findings in the TGD framework?

1. The counterpart of quenching would be conformal dissipation [L32] or equivalently p-adic occurring for mass squared scale identifiable as conformal weight rather than energy. p-Adic temperature T_p which depends logarithmically on the p-adic mass scale has a discrete spectrum and would decrease in a stepwise manner in the p-adic cooling. T_p is naturally identifiable as the temperature of the counterpart of QGP and has also an interpretation as Hagedorn temperature [**?**].

2. p-Adic length scales hypothesis [L11] suggests that there is an entire discrete hierarchy of critical temperatures rather than only a single critical temperature. These temperatures would come as logarithms of p-adic mass squared scales proportional to 2^k.

3. In the TGD framework, the large values of h_{eff} associated with the quantum criticality and implying long scale quantum coherence could explain the perfect liquid behavior in terms of long term correlations, which are typical for hydrodynamics. Recall that at the classical level TGD [K2] is essentially a hydrodynamical theory since field equations reduce to conservation laws for the charges associated with the isometries of H.

4. The TGD based explanation for the boulders flowing in the river would be that for the TGD analog of QGP, the induced Dirac equation in X^4 [L31] implies that both leptons and quarks behave like massless particles. Masses emerge only in the hadronic initial and final states constructed as modes of the H Dirac equation.

4.2 The TGD view of the RHIC findings

4.2.1 The TGD view of the standard model

My personal interest is to relate the overall view about the findings of RHIC to the TGD view about standard model interactions [L35]. This view differs rather dramatically from the standard view. It is good to start with a general summary of the TGD view of standard model physics.

1. The basic difference between standard model and TGD is due to the realization of color symmetries. In TGD, space-times are 4-surfaces $X^4 \in H = M^4 \times CP_2$ and color is not a spin-like quantum number at the fundamental level and both quarks and leptons move in spinor color partial waves defined in CP_2 [L33, L31].

   The states observable below CP_2 mass scale are color singlets consisting of color triplet counterparts of fundamental quarks and color singlet counterparts of fundamental leptons. Weak interactions can be regarded as color interactions in the "spin" degrees of freedom for CP_2 and this means unification of electroweak and color interactions [L35].

   At the space-time level spinor fields corresponding to the induced spinors are induced from second quantized H spinors, which behave like massless spinor fields. By holography= holomorphy principle the induced Dirac equation can be solved. One can also consider the possibility of Dirac equation inside causal diamond (CD). TheDirac equation in CD would involve a coupling to the Kähler structure of M^4 associated with its Hamilton-Jacobi structure [L14, L31].

2. p-Adic length scale hypothesis is a key prediction of the number theoretical vision, which in the TGD view is dual to the geometric vision of physics [L19, L28]. An entire hierarchy of standard model physics proposed to be labelled by Mersenne primes defining p-adic mass scales characterized the hadrons and also quarks. These standard model physics correspond to the hierarchy of irreducible representations of CP_2 and the multipletes for quarks and leptons are in 1-1 correspondence. Light many fermion states are color singlets [L31], which involve tachyonic fermions also allowed by the H Dirac equation. In the simplest model the tachyonic conformal weights would be associated with neutrinos. Free colored single particle states are possible only in CP_2 mass scales. Only right-handed neutrino can be color singlet.

3. A process that I call p-adic cooling [K10, K11] [L32] would characterize cosmic time evolution and mean a process in which hadrons with CP_2 mass scale decay in a cascade like matter to hadrons of light hadron physics. Needless to say that this view would revolutionize the views of cosmic evolution and astrophysics [L21, L16, L17].

4. Quantum criticality is a basic aspect of the TGD Universe and means that there are no continuously running coupling constants in the usual sense. Space-time surfaces obey holography = holomorphy principle [L22] and there is no path integral. All particles are bound states of fermions and the Feynman diagrammatics involves only fermionic 2-vertices so radiative corrections are absent [L32]. There is an analogy with Brownian motion and fermion pair creation is possible due to the existence of exotic smooth structures, possible only in the space-time dimension $D = 4$. Number theoretic vision predicts that coupling constant evolution is discrete and labelled by the p-adic length scales and possible other number theoretic parameters.

   Quantum criticality involves long range quantum fluctuations. In the number theoretic vision, they would correspond to large values of effective Planck constant h_{eff} having number theoretic interpretation either as the dimension of an algebraic extension characterizing the space-time surface or as the degree of the polynomial characterizing it.

   At quantum criticality for a phase transition changing the Mersenne prime characterizing the standard model physics large values of h_{eff} are possible and an interesting hypothesis is that there is a length scale resonance, the value of h_{eff}/h for the hadrons of the new hadron physics is such that the Compton scales for the ordinary hadrons and the hadrons of new hadron physics are the same.

5. p-Adic thermodynamics [L11] for mass squared, identified as a conformal weight, involves p-adic temperature T_p which is proportional to the inverse of the logarithm of the p-adic mass squared scale. The discreteness of the temperature conforms with the interpretation as a Hagedorn temperature [?] (see this) characterizing extended objects with infinite number of degrees of freedom. In TGD, these objects would correspond to monopole flux tubes characterizing particles and also hadrons as 3-D geometric objects. A hierarchy of Hagedorn temperatures is predicted.

   The p-adic length scale hypothesis states that primes near to some powers $p \simeq 2^k$ of 2 are physically preferred and this hypothesis has no number theoretical justification based on the naturally emerging generalization of p-adic number fields to function fields. This would suggest that the ratios of the Hagedorn temperatures are rational numbers $T_k/T_l \in \{l/k\}$.

   If the Hagedorn temperatures correspond to the temperature assigned with the high-energy collisions of nuclei, this temperature is piecewise constant and the feed of energy creates entropy but does not affect temperature. This is indeed the case: the plasma temperature assigned with the collision increases very slowly with the collision energy.

   This view leads to the notions of p-adic cooling occuring after the collision as the QGP expands and p-adic heating during which the QGP is formed [K10, K11] [L35].

6. Ordinary hadron physics would correspond to Mersenne prime M_{107} and there are indications for M_{89} hadron physics at LHC and from cosmic ray physics [K10, K11]. The proposal is that M_{89} hadron physics could play a central role in the physics of the Sun [L24].

   For the transition from M_{107} hadron physics to M_{89} hadrons physics quantum criticality, assuming that Compton lengths are same, implies $h_{eff}/h = 512$ as ration of p-adic mass scales. Interestingly, if the scaling by h_{eff}/h can occur also for the hadrons of ordinary hadron physics, the Compton length of the ordinary proton is scaled up to about 4 times Compton length of electron. This kind of scaling is assumed to occur in the TGD based model for the "cold" fusion [L1, L3, L7] as dark fusion. In the TGD based model for the Sun [L24] dark fusion would take place also at the surface of the Sun and replace the ordinary hot fusion in the solar core. It would occur after the transformation of M_{89} hadrons to ordinary hadrons by p-adic cooling at the surface of the Sun.

4.2.2 General TGD view of particle reactions

The general TGD based view of particle reactions generalizes the QCD view of hadronic reactions.

1. Interactions in H are contact interactions determined by the intersections of the space-time surfaces. Without additional assumptions the intersection consists in the generic case of discrete points. If the Hamilton-Jacobi structures are the same, the intersection consists of 2-D string world sheets whose dynamics is strongly restricted by the hypercomplex structure, meaning that only a second coordinate with light-like coordinate lines is dynamical. This is the case also in string models. By $M^8 - H$ duality a similar picture holds true also at the level of M^8 which corresponds to momentum space description for particles identified as Bohr orbits of 3-surfaces.

2. There would be two phases: X^4-phase as the counterpart of QGP but involving only free quarks and H-phase as counterpart of hadron phase. Hadronization leading from QGP the final state and the generation of the analog of QGP phase from hadronic initial state generalize to all standard model interactions and are universal mechanisms [L35].

3. The role of ZEO is essential. ZEO involves two kinds of state function reductions (SFRs). "Big" SFRs (BSFRs) and "small" SFRs (SSFRs). SSFRs are self measurements in the non-deterministic degrees of freedom assignable to the space-time surfaces $X^4 \subset H$ obeying holography = holomorphy principle and therefore being analogous to Bohr orbits for particles as 3-surfaces. Sequence of SSFRs defines a conscious entity, self. Slight classical non-determinism of holography= holomorphy vision accompanied by quantum non-determinism essential also for the particle reactions.

   In BSFR which is the TGD counterpart for the ordinary measurement reducing the entanglement between observer and the systems, the arrow of time changes. In a hadronic reaction two BSFRs take place. In the first BSFR a p-adic cooling in a reversed time direction occurs. For an external observer it looks like heating of the system. After the second BSFR p-adic cooling in standard time direction takes place. Conformal dissipation is involved with the cooling.

4.2.3 Conformal dissipation, p-adic length scale hypothesis and quantum ciriticality

Could quantum quantum criticality involving conformal invariance and quantum coherence play a central role in jet quenching. $M^8 - H$ duality inspires the notion of conformal dissipation [L32] as a dissipation in which energy is replaced with conformal weight, which is essentially mass squared. Could conformal dissipation interpreted as p-adic cooling help in the attempts to understand quenching?

1. Conformal dissipation [L32] is suggested by the $M^8 - H$ duality and would be described in terms of 4-surface Y^4 in M^8 as dual of space-time surface and defining the analog of momentum space defining dispersion relation. The time evolution at space-time level would correspond to p-adic momentum space evolution as a decrease of the mass scale and ending up to an evolution at mass shells of final state particles identifiable as ordinary dissipation. This could correspond to p-adic cooling. p-Adic heating can be considered would correspond to p-adic cooling with a reversed arrow of time and occur after the first BSFR. The p-adic cooling could be synonymous to a conformal dissipation.

2. Two kinds of number theoretic phase transitions and their combination are possible. The decrease of the p-adic mass scale of hadrons and quarks can take place as the collision energy increases. Quantum criticality in turn induces the increase of h_{eff}. A physically attractive proposal is that the increase of h_{eff} compensates the decrease of the Compton scales due to the shortening of the p-adic length scale. Frequency and wavelength resonance between initial and final states would become possible.

3. The TGD based proposal is that the Nature is theoretician friendly [K6] [L12]: when interactions get so strong that perturbation series fails to converse, a phase transition increasing the value of h_{eff} takes place implying the reduction of α_s. This allows converging perturbation

series but the states are changed. Also the interaction range as a scale of quantum coherence increases. This could lead to the formation of perfect liquid.

Also the Compton scales of quarks could increase. For 4 MeV quark the Compton scale for $h_{eff}/h = 512$ corresponding to M_{89} and scaling by $h_{eff} = 512h$ would be proton Compton length.

4. The basic steps of the process would be p-adic heating as a cooling with a reversed arrow of time initiated by the first BSFR followed by p-adic cooling initiated by the second BSFR. Cooling would be a stepwise process and there would be a hierarchy of criticalities. Are p-adically scaled up variants of hadron physics with $p \simeq 2^k$ for all values of k be involved as intermediate states in the cooling and heating. Or are only those values of k which can be assigned with quarks involved?

   Sequence of critical temperatures depending logarithmically on the p-adic mass scale increasing as powers of 2. The fact that T_p has logarithmic dependences of the discrete p-adic mass scale would explain the bumpiness at low energies.

5. What p-adic temperature does the mass scale 19.6 GeV correspond to? p-Adic length scale hypothesis predices $T = log((M/m_p)^2/log(2)$. This predicts $T(19.6GeV) = 214.5$ MeV, which is surprisingly near to the estimate for QCD Λ. p-Adic cooling suggests that the bumpiness between 3.6 GeV and 20 GeV could correspond to sequence of phase transition temperatures $T(127-k)$, $k = 4,5,6,7,8$. For 200 GeV energy one would have $T \sim 379.36$ MeV. Note that M_{89} hadron physics corresponds to a considerably lower temperature $T = 285.39$ MeV.

   It should be also noticed that quite recently 20 GeV gamma rays have been reported (see this). This is discussed in [K5]. In TGD they could correspond to decay products of a pion-like state with mass of 40 GeV about 286 pion masses.

4.2.4 Heavy ion collision as a p-adic heating followed by p-adic cooling

enumerate

p-Adic mass scale as octaves or half octaves 2^k. The most general option is that all values of k are possible. p-Adic length scales come as powers of 2 for odd k and of $\sqrt{2}$ in the general case! The strongest restriction is that the p-adic primes correspond to Mersenne primes for stable hadrons and leptons. The transitions between these M_{89} hadron physics and M_{107} hadron physics could occur via p-adic cooling via unstable intermediate states as cascades in with k decreases in a stepwise manner.

The p-adic temperature T_p appearing in p-adic mass calculations corresponds to the integer valued inverse temperature of p-adic thermodynamics for mass squared identified as conformal weight is naturally identifiable Hagedorn temperature. Since Boltzman weights as exponential $e^{-E/T}$ are for number theoretical existence reasons replaced by powers p^{m^2/T_p}, $T_p = 1/n$, the real counterpart of $1/T_p$ $k/log(p)$ meaning that it depends logarithmically on mass squared scale. For fermions $k = 1$ is realized.

Conformal invariance motivates the guess that T_p corresponds to the hadronic temperature T. p-Adic temperature is not the same thing as the ordinary temperature. T_p scales like $1/log(p) \propto 1/k$ if the p-adic length scale hypothesis $p \simeq 2^k$ and supported by the function field generalization of p-adic numbers holds true.

$1/p$ scales like mass squared and p-adic temperature T_p scales like logarithm of the mass squared scale and is discrete. If the p-adic length scale hypothesis is true, the ratio of p-adic temperatures equals to $T_k/T_l = l/k$. The piecewise constancy justifies the interpretation as Hagedorn temperature. For instance, $T_{89}/T_{127} = 127/89 = 1.42$ so that the scaling is very slow. M_{89} corresponds to 284 MeV if M_{107} corresponds to 200 MeV.

Quantum criticality is associated with the transition changing the p-adic length scales Compton lengths for the scaled up hadron physics would be the same as for the M_{107} hadron physics at quantum criticality. Critical points could correspond to the temperatures of quark gluon plasmas characterized by the p-adic temperature depending logarithmically on the p-adic mass scale. This predicts that critical collision energies $\sqrt{s_{NN}}$ come as powers of 2.

4.3 Official top quark and toponium as particles of M_{89} hadron physics?

I watched an excellent video about what we have learned at LHC (see). Three runs RUN1, RUN2, and RUN3 have been completed and now we know where the limits for the applicability of the Standard Model are.

The immediate successor of LHC will be high-luminosity LHC operating from 2029- 2030 onwards for ten years. Future circular collider (FCC) will start to operate in the late 2040s. Electrons and positrons will collide and the collider (Higgs factory) will act as a high precision collider.

The philosophy is that high precision might allow us to develop a theory allowing us to solve the various anomalies of the standard model. In future, the experimentalists would not be merely testing whether a given extension of the standard model might solve some anomalies but trying to identify more general deviations from the standard model. But is this enough? What has been lacking from theoretical physics since the times of Einstein and his contemporaries, is philosophical thinking challenging the basic assumptions. Can one make progress by merely measuring more precisely?

The video explains the basic anomalies. The anomalies are also discussed in detail by Crivellin and Mellado [C5]. The following list defines the boundaries of the region of phenomena that the standard model can explain.

1. Toponium exists although it should not.
2. W mass deviates from the predicted mass.
3. g-2 anomaly of muon is claimed to disappear in lattice calculations using only quarks and gluons but does not disappear when hadronic data are used as an input.
4. Lepton universality is violated in some meson decays.
5. Penta and tetra quarks, whose existence is not denied but not predicted by the standard model.
6. There are anomalies associated with the CP violation of the CKM matrix.
7. The axions, proposed to solve the problem due to the strong CP violation predicted by QCD, have not been found and the strong CP violation is too weak to explain matter antimatter asymmetry.
8. Quark-gluon plasma predicted by QCD did not behave like gas but a perfect liquid and the transition to quark gluon plasma seems to occur at several energies rather than single phase transition point.
9. SUSY was believed to solve the hierarchy problem involving the fine tuning of the Higg couplings but no evidence for SUSY particles was found.
10. WIMPs as candidates for galactic dark matter have not been found.

5 Toponium anomaly as an indication for M_{89} hadron physics

I have discussed various anomalies from the TGD point of view in various articles. Here I will consider only the discovery of the toponium, which is one of the latest surprises.

5.1 What toponium is?

The Standard model does not deny toponium's existence but according to the standard intuition it should not exist.

1. The lifetime of the top quark is too short for the formation of toponium. There are of course proposals for solving this and also other anomalies but the problem is that these proposals typically solve only one anomaly. The lifetime of the standard top quark candidate with

mass $m \simeq 172.5$ GeV is $\tau = 5 \times 10^{-25}$ s. This time is shorter than required for QCD hadronization processes ($10^{-23} - 10^{-24}$ s). This is why it has been believed that toponium does not exist.

2. The toponium was however discovered both by LHC and ATLAS and its lifetime is estimated to be 2.5×10^{-25} s. Toponium is suggested to be a quasi-bound state or a resonance appearing when top quarks are produced very near to the threshold energy (see this and this). Toponium decay is triggered by a weak decay of one of its constituents rather than being a strong decay. Both ATLAS and CMS verified the existence of this state with a resonance width of about 3 GeV.

5.2 TGD predicts a fractal hierarchy of standard model physics

Consider now the basic ideas of TGD view of hadron physics and standard model in general. TGD leads to almost inescapable conclusion that there must exist an entire hierarchy of standard model physics assignable to the triality ± 1 color representations defined by color partial waves of quarks and antiquarks in CP_2. Leptons would appear in triality 0 color partial waves [L33, L31].

1. The color multiplets of quarks of a given standard model physics would combine to form color triplets, which would serve as building bricks of hadrons of a given hadron physics [L35, L41, L30, L40]. These hadrons would correspond to a hierarchy of p-adic mass scales, proposed to be labelled by ordinary and Gaussian Mersenne primes. The longer the p-adic scale, the higher the dimension of the color multiplet.

   For the observed leptons, color representations would combine to form color singlets but also analogs of mesons as bound states of colored leptons might be possible [K19]. Only at energies near CP_2 mass would color deconfinement for incoming and outgoing states be possible.

2. Ordinary hadrons would correspond to the Mersenne prime M_{107}. The nucleon of M_{89} hadron physics would correspond to the mass scale $512 m_n$ and therefore to the LHC energy scale. The transition from M_{107} hadron physics to M_{89} hadron physics would take place at quantum criticality. The phase transition usually interpreted as a creation of the quark-gluon phase could correspond to this phase transition [L38]. At quantum criticality the value h_{eff}/h would scale up the Compton length scale of M_{89} hadrons. This would reflect long range quantum fluctuations. This re-interpretation of what has been identified as quark gluon-plasma would solve various anomalies associated with this identification mentioned already in the list of anomalies [L38, L35]. The existence of M_{89} hadron physics can have dramatic implications. For instance, a dramatic modification of the model of the Sun [L24] can be considered.

3. The ratio of the p-adic length scales associated with M_{107} and M_{89}, characterizing the Compton lengths and also defining the geometric size of nucleons as 3-surfaces, is 512. The assumption is that the geometric size of the M_{89} hadron with a large h_{eff} is the same as for M_{107} hadron at quantum criticality implies $h_{eff}/h = 512$. The sizes of M_{89} hadrons would be the same as for ordinary hadrons at quantum criticality for the transition from M_{89} hadron physics to M_{107} hadron physics.

4. I have proposed the identification of various bumps observed at LHC, originally identified first as candidates for SUSY particles but then rejected, in terms of M_{89} mesons [K10, K11].

5.2.1 Could the official top quark be a quark of M_{89} hadron physics?

The large mass of the official top quark raises the question whether it could be M_{89} quark created at quantum criticality.

1. A natural guess is that the lifetime of top quark at quantum criticality is scaled up $h_{eff}/h = 512$ to $.25 \times 10^{-21}$ s. The corresponding distance scale would be $.75 \times 10^{-13}$ m, which is longer than the nuclear size scale!

2. A reasonable guess is that the hadronization time scale for M_{89} is for h_{eff}/h scaled down by factor 1/512 due to decrease of the p-adic length scales. This p-adic length scale corresponds to the geometric size scale of the causal diamond $CD = cd \times CP_2$ assignable to the region in which the phase transition occurs. This local phase transition is discussed in [L41]. The increase $h_{eff} \rightarrow 512h_{eff}$ keeps the geometric time scale associated for hadronization the same as it would be for ordinary hadrons and determined by the p-adic time scale $L(107)$ assignable to ordinary hadrons.

   What happens to the rate of hadronization? The phase transition increasing the value of h_{eff} guarantees that the TGD counterpart of perturbative theory,, still applies. "Mother Nature loves her theoreticians" [L12] is one way to express this principle. Since the zeroth order term in the TGD counterpart of the perturbative expansion, giving the classical approximation, does not depend on h_{eff}, the classical approximation improves as h_{eff} increases.

   The rate for M_{89} hadronization is proportional to the hadronic mass scale $m(89) = 512m(107)$. Since the geometric time scale is $L(107)$ by quantum criticality, the short lifetime of top does not prevent the formation of toponium. Quantum criticality could quite generally increase the probabilities for the formation of bound states of very short-lived particles.

The basic objection is that the official top quark as M_{89} quark would most naturally correspond to some M_{107} quark. The actual $g = 2$ U type quark should have a lower mass that the official top quark.

1. There is indeed evidence for a top quark-like state at much lower mass from Aleph. The mass is estimated to be about 30 GeV or 28 GeV [C1]. This has motivated the question whether the two candidates for the top quark could correspond to a scaled variant of the top. In the TGD framework, the p-adic length scale hypothesis might allow this [K10] [L30].

2. What about the toponium in this case? There is an old anomaly reported by Aleph at 56 GeV (see `https://arxiv.org/pdf/hep-ph/9608264.pdf`) and there is reference to an old paper: ALEPH Collaboration, D. Buskulic *et al*, CERN preprint PPE/96–052. What was observed was 4-jet events consisting of dijets with invariant mass around 55 GeV. What makes this interesting is that the mass of 28 GeV particle candidates would be one half of the mass of a particle with a mass of 56 GeV particle, quite near to 55 GeV. Could this state be the toponium as $g = 2$ U quark [K10] [L30]?

From the ratio 512 of the mass scales for M_{89} and M_{107} hadron physics one can estimate the mass of M_{89} top quark to be in the range 1450-1500 GeV. By using the scaling argument it is possible to also estimate the masses of the M_{89} quarks. Here a report about finding dark matter candidate at LUX-ZEPLIN detector came in rescue.

5.2.2 The dark matter particle detected by the LUX-ZEPLIN detector is identifiable as a dark pion of M_{89} hadron physics predicted by TGD!

It took 5 months for me to learn of a claim about a direct detection of dark matter. The news was published already towards the end of 2025 (see this). I will glue part of the news here.

The LUX-ZEPLIN detector (see this) at the Sanford Underground Research Facility, located 1,500 meters beneath the former Homestake Gold Mine, recorded 8 candidate dark matter interaction events over 1,000 days of operation that carry statistical certainty of 5.2 sigma crossing the discovery threshold physicists require for particle physics announcements. The detector uses 10 tonnes of ultra-pure liquid xenon cooled to minus 108 degrees Celsius, surrounded by water tanks shielding against cosmic rays that would overwhelm the faint dark matter signal at shallower depths.

Dark matter particles theorized as Weakly Interacting Massive Particles with masses between 10 and 1,000 times the proton mass produce tiny flashes of scintillation light and ionization when they collide with xenon nuclei, distinguishable from radioactive background through their characteristic dual-signal fingerprint.

The detected events carry particle masses consistent with a 65 proton-mass dark matter candidate, within the theoretical range predicted by supersymmetric extensions of the standard model. Independent verification is already underway at the PandaX-4T detector in China and the XENONnT detector in Italy's Gran Sasso Laboratory, with results expected within six months.

What does TGD say about the claimed 5.2 sigma discovery?

1. One of the most dramatic predictions of TGD is a scale hierarchy of standard model physics labelled by Mersenne primes and their Gaussian counterparts [L33, L31, L35] based on number theoretic vision [L19, L28]. This hierarchy would correspond to the hierarchy of color partial waves associated with the Dirac equation in $H = M^4 \times CP_2$ in which space-times are 4-surfaces obeying a slightly non-deterministic holography. The failure of strict classical determinism of the holography at the level of space-time surfaces, forcing what I call zero energy ontology (ZEO), is crucial for both the non-triviality of quantum TGD and for TGD inspired theory of consciousness.

   The mass scales of leptons and hadrons of a standard model physics associated with a given pair of quark-like and leptonic color partial wave multiplets is conjecture to be proportional to the inverse of the square root of the Mersenne or Gaussian Mersenne characterizing the scaled copy: for the most recent articles about p-adic thermodynamics, replacing Higgs mechanism [L11, L30, L40]. For instance, for electrons one would correspond to Mersenne prime $M_{127} = 2^{127} - 1$.

2. Ordinary hadrons would correspond to Mersenne prime $M_{107} = 2^{107} - 1$. The Mersenne prime M_{89} would correspond to a mass scale, which is 512 times the mass scale of ordinary hadron physics. During about 2 decades pieces of evidence for M_{89} hadron physics at LHC have been accumulating [L35] [**?**, K11]. M_{89} hadron physics would dramatically modify the model for the energy production in the Sun [L24].

3. TGD predicts a hierarchy of effective Planck constants h_{eff} coming as integer multiples of its minimal value, which is considerably smaller than the ordinary Planck constant. The phases with non-standard value of Planck constant would behave like dark matter since vertices involving fermions with particles having different values of h_{eff} are not possible. The 2-vertex changing the value of h_{eff} is however possible and phase transitions changing h_{eff} are possible.

4. A TGD based explanation for the LUX-ZEPLIN events interpreted in terms of dark matter would be as a pion of M_{89} hadron physics identifiable as a scaled up copy of ordinary M_{107} hadron with a mass scale which is 512 times higher but having a non-standard value of effective Planck constant so that the M_{89} hadrons would be like dark matter. The scaling of the mass .134 MeV of the ordinary pion by factor 512 gives mass of 67 GeV. This is exactly the reported mass if proton mass 940 MeV is approximated as 1 GeV (the error is 6 per cent)!

   M_{89} hadrons would be created as a phase of ordinary matter with scaled up valued of effective Planck constant guaranteeing that at quantum criticality for the phase transition the Compton lengths of M_{89} hadrons, scaled by factor h_{eff}/h are same as for ordinary hadrons. This requires that the ratio of h_{eff}/h equals to the ratio p-adic length scales associated with M_{107} and M_{89} equal to $2^{(107-89)/2} = 2^9 = 512$.

One can apply the scaling argument to estimate masses of the scaled variants of other quarks.

The mass of M_{89} s quark would be 176 GeV, which is not far from top quark mass $m_t = 173$ GeV. The original proposal that the top quark corresponds to M_{89} u quark. I did not realize that the scaling argument allows only the interpretation as M_{89} s quark.The mass of c quark is estimated to be 1.5 GeV or 1.275 GeV. The M_{89} c quark is estimated to have mass of 750 GeV or 63.75 GeV. The mass of b quark is estimated to be in the range 4.2-4.7 GeV M_{89} b quark is estimated to have mass in the range 2400 GeV-2350 GeV. If the real top has mass of 28 GeV or 30 GeV explaining the Aleph anomaly, the mass of M_{89} t quark is in the range 1400-1500 GeV.

These kind of estimates can be made also for leptons and baryons. M_{89} electron would have mass about 250 GeV. The naive scaling of proton mass would give the mass of 512 GeV for M_{89} nucleon. Needless to say, these predictions mean an entire scaled hadron physics to be tested at LHC.

If this picture is correct, the official top quark would more naturally correspond to genus $g = 1$ and therefore to M_{89} s quark. Could the poor understanding of the family replication phenomenon and of the origin of the CKM mixing explain this mis-interpretation?

1. The CKM matrix V is empirically determined from charged currents (W decays). The matrix elements of type V_D^U, $U \in \{u, c\}$, $V \in \{d, s\}$ reflect the CKM mixing of d and s quarks. Unitary conditions bring in the matrix elements V_D^t and dependence on top quark mass. Both beta decays and kaon decays provide information about V_D^U, $U \in \{u, c\}$, $V \in \{d, s\}$. These two kinds of constraints lead to slightly different outcomes [C5] for V.

2. Could a wrong identification of the top quark mass cause the discrepancy? In TGD, the official top as the $g = 0$ quark of "dark" M_{89} hadron physics created in the transition to quark-gluon plasma would induce a leakage of probability inducing a genuine violation of the unitary for the CKM matrix.

3. In TGD, the description of family replication has a topological explanation and CKM mixing reduces to topological mixing discussed in [K3, K13]. A model for the transition between M_{107} and M_{89} is needed to see whether the new interpretation can be consistent with what is known about creation of official top quarks.

4. The prediction is that the official top as an M_{89} s quark is accompanied by an M_{89} c quark with considerably large mass. The toponium as a counterpart of neutral K meson should be a member of an isospin doublet. There should be two doublets and CP breaking at the level of M_{89} hadron physics. In particular, toponium should have short lived and long lived versions with slightly different life times.

   The M_{89} counterparts of various mesons such as π and ρ should exist and the mass of the recently discovered dark matter candidate indeed has an identification as the M_{89} variant of pion. The discovery of the M_{89} counterpart of the hadron spectroscopy would give a dramatic support for the TGD view.

6 The problem of time and the TGD counterpart of $F = ma$

This contribution was inspired by a posting of Lawrence B. Crowell related to one particular problem related to the notion of time in general relativity: the general coordinate invariance implies interpretational problems since it is difficult to identify any preferred time coordinates used by observers. The identification of spatial coordinates is problematic for the same reason.

There are also other deep problems. In curved space-time classical conservation laws are lost. Einstein's equations are formulated in terms of energy momentum tensor but Newton's equations ($F = ma$) expressing the conservation of momentum and energy cannot be formulated in a general coordinate invariant way since the notions of energy and momentum fluxes are lost.

TGD view of the problem of time inspired Lawrence B. Crowell to ask about the TGD counterpart of $F = ma$. This question can be abstracted to the question about how the transfers of conserved isometry charges of $H = M^4 \times CP_2$ are realized at the level of fundamental interactions. At this level the question is about how the conserved charges associated with the initial state particles are redistributed between the final state particles.

Somewhat surprisingly, TGD based quantum ontology [L6, L18] implies that quantum non-determinism is an essential part of the answer to the question. Equally surprisingly, also a connection with the theory of consciousness and cognition emerges at the fundamental elementary particle level as also realized in [L30].

A detailed consideration of the question of Crowell led to a considerable clarification of the previous views. In the TGD view, the weak violation of the classical non-determinism in holography = holomorphy vision of TGD leads to the identification of self as a sequence of "small" state function reductions (SSFRs) identified as TGD counterparts of repeated measurements of the same observables: now however the observables related to the non-determinism are measured in SSFRs and give rise to the correlates of cognition. By quantum criticality, a "big" state function reduction (BSFR) as the TGD counterpart of what occurs in quantum measurement, can take place. BSFR means the death of self and its reincarnation with an opposite arrow of time.

Quantum criticality of the TGD Universe, realized in terms of holography = holomorphy principle, would be essential for this. For instance, particle decay could correspond to this process and all particle interactions would basically be due to the quantum criticality so that instead of SSFR, BSFR takes place. Intention is transformed to action. Thinking is dangerous in the TGD Universe!

6.1 From the problem of time in general relativity to the TGD counterpart of $F = ma$ as a general view of particle reactions

In the sequel the arguments inspired by the discussion about time and the TGD counterpart of $F = ma$ with Lawrence B. Crowell are summarized. What is new from the point of view of TGD is that the role of quantum criticality in quantum measurement is considerably clarified. Also the very close relationship of fundamental physics with cognition and intentionality in the TGD Universe becomes concrete: also particle reactions can be see as intentions transformed to actions.

6.1.1 The 3 problems related to the notion of time

It is good to beging with my first comment to the posting of Lawrence B. Crowell.

1. In the materialistic ontology subjective and geometric time are identified and this leads to deep problems.

   In TGD zero energy ontology [L6, L15] allows both times and solves both the measurement problem and the problem of free will. Subjective time corresponds to a sequence of "small" state function reductions (SSFRs) replacing the Zeno effect, in which nothing happens, with the notion of self.

   Zero energy ontology replaces space-time surfaces as analogs of Bohr orbits for 3-surfaces having an interpretation as a geometric representation of particles. The classical dynamics is slightly non-deterministic although field equations are satisfied. This has crucial implications for the description of fundamental interactions [L28, L35]. This non-determinism also makes possible the description of physical correlates of cognition.

2. The second problem relates to the geometric time. General coordinate invariance allows an endless number of identifications of the time coordinate. In TGD, space-times are 4-surfaces in $H = M^4 \times CP_2$ and M^4 provides linear Minkowskian time or light-cone proper time (cosmic time) as a preferred time coordinate for the space-time surfaces.

3. The loss of Poincare invariance in General Relativity is the third problem and led to TGD. In TGD one obtains classical conservation laws due to the Poincare invariance of M^4 factor of H.

6.1.2 What does $F = ma$ mean in TGD?

Lawrence B. Crowell asked about how the counterpart of $F = ma$ emerges in TGD. At the general level the answer is as follows.

1. $F = ma$ states momentum conservation for a particle plus its environment by characterizing the momentum is exchanged between the particle and environment. In TGD, momentum conservation generalizes to field equations for the space-time surfaces as analogs of Bohr orbits of particles identified as 3-surfaces. The field equations state the conservation of Poincare and color charges classically.

   Unlike in General Relativity, Newton's equations at the fundamental level are therefore not given up in TGD and their generalization defines the dynamics of space-time surfaces [K2]. Therefore TGD is formally like hydrodynamics.

   Einstein's equations follow naturally at the QFT limit as a remnant of Poincare invariance when the sheets of the many-sheeted space-time are replaced with a slightly curved region of M^4 carrying the sum of induced gauge fields and gravitational fields defined as deviation from M^4 metric.

2. This can be made much more precise. Holography = holomorphy (H-H) hypothesis [L28, L22, L37] reduces the field equations to local algebraic equations in terms of generalized holomorphy irrespective of action as long as it general coordinate invariant and expressible in terms of the induced geometry. This generalizes the role of holomorphy in string models.

   In conformal field theories, holomorphy serves as a correlate for 2-D criticality. In TGD it would be a correlate for quantum criticality in the 4-D sense. This principle is extremely powerful since various dynamical parameters are analogous to a critical temperature.

   Space-time surfaces as minimal surfaces become analogs of Bohr orbits. Minimal surface equations generalize massless field equations and the TGD counterparts of field equations of gauge theories follow automatically.

3. Holomorphy is violated as 3-D surfaces, which are analogous to the singularities of analytic functions. This can be seen as a generalization of the fact that analytic functions can be expressed in terms of the holographic data given at poles and cuts.

4. What is crucial is that there is a slight failure of determinism (but not of field equations). This occurs also for soap films, modellable as 2-D minimal surfaces: the frames do not uniquely determine the soap film. In TGD, the identification of this non-determinism as a p-adic non-determinism is attractive and leads to a generalization of the notion of p-adic number field to a function field [L28, L36].

   H-H vision leads to a long-sought-for understanding of the origin of p-adic length scales hypothesis which for 30 years ago led to a surprisingly successful particle mass calculations based on p-adic thermodynamics [K9, K3] [L11]. The most recent article is about the application to the calculation of the mass spectrum of quarks and hadrons [L30]. The p-adic non-determinism and p-adic length scale hypothesis would have origin in the iterations of polynomials defining dynamical symmetries in H-H vision and also giving a connection to the Mandelbrot fractals and Julia sets becomes possible.

6.1.3 Geometric and fermionic counterparts of $F = ma$ in TGD

The next question concerns the counterpart of $F = ma$ at geometric and fermionic levels respectively.

$F = ma$ is a simple model for interactions. How are the interactions of two space-time surfaces A and B as analogs of Bohr orbits described geometrically?

1. Geo H^k metric vision suggests that a generalization of a contact interaction is in question. The intersection of A and B defines the contact points. Without additional assumptions the intersection of A and B would be a discrete set of points. One can argue that this is not enough.

2. The intuitive idea is that there must exist additional prerequisites for the formation of a quantum coherent structure, at least in the interaction region. The proposal is that A and B share a common generalized complex structure, which I call Hamilton-Jacobi structure [L14] so that the conformal moduli defining the H-J structure would identical.

   The common H-J coordinates involve hypercomplex coordinate pair u, v with light-like coordinate curves, common complex M^4 coordinate w and common complex CP_2 coordinates. The analytic functions defining A and B as their root must be generalized analytic functions of the same H-J coordinates.

3. The solution of field equations in Minkowskian space-time regions implies that either u or v is a passive coordinate since it cannot appear in the generalized analytic functions (the real hypercomplex coordinates u and v are analogous to z and $\overline{z}$). The 2-D surfaces at which u and v vary, are generalizations of straight strings of M^4 and dynamically very simple. Vibrational string degrees of freedom are frozen but the string ends at the partonic orbits are dynamical and can carry fermion numbers.

   In this case, the intersection of A and B consists of 2-D string world sheets connecting light-like partonic orbits. This gives a connection with string model type description.

4. Self-interactions of the space-time surface correspond to self-intersections consisting of string world sheets. For instance, the description of the internal dynamics of hadrons [L35, L30] is realized in terms of self-intersections.

In the fermionic sector modified/induced Dirac equation at the space-time level holds true for the induced spinor fields and can be solved exactly by the holomorphy just as in the case of string models. At the level of scattering amplitudes the dynamics reduces to the fermionic N-point functions.

Propagators are free propagators in H and the hard problem is to understand how fermion pair creation is possible when fermions are free in H. The notion of exotic smooth structure, possible only for 4-D space-time surfaces, solves the problem.

6.1.4 How to translate F=ma to a view about the transfer of isometry charges between initial and final state particles?

Let us return to the original question. How can one understand the generalization of $F = ma$ in terms of a transfer of isometry charges of A (momenta color charges) from the initial state particles A and B to the final state particles? The classical field equations state the local conservation of isometry currents. How can this give rise to a transfer of total charges?

1. In the interaction region the Hamilton-Jacobi structures for A and B must be identical. Intersection consists of string world sheets. The interacting state therefore differs from the non-interacting state. Intuitively it is clear that the incoming states in the distant geometric past approach disjoint Bohr orbits. This is true also in the remote future except that the scattering need not be elastic and the particles identifiable bremsstrahlung can be emitted in the interactions. The interaction can also induce the decay of A and B. What happens in hadronic reactions gives a good idea of what happens.

2. The key notion is the mild failure of classical determinism for the Bohr orbits, which also characterizes criticality. The minimal surfaces describing the space-time surfaces have 3-D loci of non-determinism at which the classical determinism fails. These loci are analogous to the 1-D frames spanning 2-D soap films, which are also slightly non-deterministic minimal surfaces. There are several soap films spanned by the same collection of frames. The non-determinism gives rise to a sequence of small state function reductions (SFRs) generalizing the Zeno effect of standard quantum mechanics.

6.1.5 The description of the scattering in space-time degrees of freedom

Consider first the situation for a single particle as a 4-D Bohr orbit.

1. The non-determinism gives rise to internal interactions assignable to the self intersection as string world sheets. In the TGD inspired theory of consciousness, they can be identified in terms of geometric correlates of cognition.

2. Thinking is however dangerous also at the elementary particle level! The non-determinism is associated with quantum criticality and can lead to the decay of a partonic orbit to two or even more pieces. It can also change the topology of the partonic 2-surface characterized by genus g (CKM mixing). The partonic decay can in turn induce the decay of the space-time surface itself. The outcome would be a particle decay.

   This also leads to an emission of virtual particles as Bohr orbits, which appear as exchanges in 2-particle interactions. Massless extremals/topological light rays [K14] as counterparts of massless modes of gauge fields can be emitted. Closed 2-sheeted monopole flux tubes as geometric particles can be created by a splitting of a single monopole flux pair by a reconnection: this would be involved with a particle decay and emission of a virtual particle.

3. The scattering of two interacting particles A and B reduces to self interaction in the interaction region behaving like a single particle. The slight non-determinism makes possible a geometric generalization of the Feynman diagram type description. Now however all would be discrete and finite. There would be no path integral and therefore no divergences.

The outcome would be a classical description and the generalization of $F = ma$ would code for the transfers of isometry charges from A and B to the final state particles generated in the scattering. The slight classical non-determinism would make this possible.

6.1.6 The description of the scattering in fermionic degrees of freedom

The description of the scattering in fermionic degrees of freedom involves highly non-trivial aspects.

1. In the fermionic degrees of freedom, the fermionic propagators between points of the singular 3-surfaces defining the interaction vertices as ends of string world sheets of the intersection would describe the situation.

2. The crucial point is the possibility of fermion pair creation only for 4-D space-time surfaces due to the existence of the exotic smooth structures [A3, A4, A1] discussed from the TGD point of view in [L27, L10, L22, L10, L27, L5]. In other space-time dimensions the fermions would be free.

3. Fermion pair creation corresponds intuitively to the turning of a fermion line in time direction. At the 3-D holomorphic singularities X^3 (analogous to cuts of analytic functions) the minimal surface equations fail and the additional pieces of the classical action, in particular 4-volume as the analog of cosmological constant term, become relevant. The twistor lift of TGD [K18, K16] implies that the action is sum of Kähler action and volume term.

4. X^3 represents a defect of the standard smooth structure and the turning of a fermion line at X^3 at which standard smoothness fails corresponds to the transformation of u-type coordinate curve to a v-type coordinate curve takes place in the pair creations. u and v are associated with the parallel Minkowskian space-time sheets of the 2-sheeted space-time region. The creation of fermion occurs at the boundaries of two string world sheets at different monopole flux tubes so that a decay of monopole flux tube to a pair of them occurs.

   The pair creation would take place in the interaction regions and lead to the generation of final state fermions as the decay to 3-surfaces takes place. Closed 2-sheeted monopole flux tubes carrying fermion lines at their ends defined by Euclidean wormhole contacts connecting two sheets are generated.

5. At the 3-D defects minimal surface property fails and the trace of the second fundamental form, call it H^k, which vanishes almost everywhere, has a delta function singularity. By its group theoretical properties H^k has an interpretation as a generalized Higgs field. What is new is its M^4 part, which has an interpretation as a local acceleration for a 4-D Bohr orbit. The same interpretation applies to the TGD counterpart of the ordinary Higgs.

6. The vertices at 3-D singularities are analogous to points at which the direction of the motion for a Brownian particle changes. Conformal invariance suggests that the 8-D Higgs vector H^k is light-like so that one has $H_kH^k = 0$. Higgs has the dimension of $\hbar$/length and its vanishing gives rise to the analog of 8-D massless fixing M^4 mass squared in terms of CP_2 mass squared. A reasonable guess is that the square of M^4 part of H^k is proportional to particle mass squared. This would give rise to quantum-classical correspondence.

6.1.7 Possible implications for the TGD inspired theory of consciousness

In TGD, consciousness and cognition are assigned with the internal degrees of freedom (IDF) assignable with the classical non-determinism. Ordinary SFRs (BSFRs) are assigned with the ordinary degrees of freedom (ODF) assignable to the entire Bohr orbits and measured in the ordinary quantum measurements. Several questions related to the relationship of IDF and ODF) come to mind.

Consider two systems A and B.

1. The IDF of A need not entangle with the ODF of A although the ODF of A and B can entangle. Could this relate to sensory perception?

2. The IDF of A can entangle with the ODF B. Could this make possible psychokinesis and hypnosis?

3. The IDF of A and B can entangle. Could this relate to telepathy?

4. Entanglement can also occur between the IDF and ODF of A. Could this relate to the realization of intentions in motor degrees of freedom?

The precise role of quantum criticality should be understood. Conservation laws pose strong restrictions here: a stable particle like proton or electron serves as an example. The intuitive idea is that a perturbation is needed to trigger a BSFR, which transforms intention realized as entanglement to a motor action or to an action affecting the external world. Is the quantum entanglement of IDF with its ODF enough to trigger a BSFR of the system: a spontaneous decay of an unstable particle would be an example now.

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