TGD inspired vision about entropic gravitation

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1 Introduction

Entropic gravity (EG) introduced by Verline [23] has stimulated a great interest. One of the most interesting reactions is the commentary of Sabine Hossenfelder [19]. The article of Kobakhidze [20] relies on experiments supporting the existence of Schrödinger amplitudes of neutron in the gravitational field of Earth develops an argument suggesting that EG hypothesis in the form in which it excludes gravitons is wrong. Indeed, the mere existence of gravitational bound states suggests strongly the existence of transitions between them by graviton emission. The following arguments represent TGD inspired view about what entropic gravity (EG) could be if one throws out the unnecessary assumptions such as the emerging dimensions and absence of gravitons.

1. If one does not believe in TGD, one could start from the idea that stochastic quantization or something analogous to it might imply something analogous to entropic gravity (EG). What is required is the replacement of the path integral with functional integral.

2. Holography requires that everything reduces to the level of 3-metrics and more generally, to the level of 3-D field configurations. Something like this happens if one can approximate path

integral integral with the integral over small deformations for the minima of the action. This also happens in completely integral quantum field theories.

The basic vision behind quantum TGD is that this approximation is much nearer to reality than the original theory. In other words, holography is realized in the sense that to a given 3-surface the metric of WCW assigns a unique space-time and this space-time serves as the analog of Bohr orbit and allows to realize 4-D general coordinate invariance in the space of 3-surfaces so that classical theory becomes an exact part of quantum theory. This point of view will be adopted in the following also in the framework of general relativity where one considers abstract 4-geometries instead of 4-surfaces: functional integral should be over 3-geometries with the definition of Kähler metric assigning to 3-geometry a unique 4-geometry.

3. A powerful constraint is that the functional integral is free of divergences. Both 4-D path integral and stochastic quantization for gravitation fail in this respect due to the local divergences (in super-gravity situation might be different). The TGD inspired approach reducing quantum TGD to almost topological QFT with Chern-Simons term and a constraint term depending on metric associated with preferred 3-surfaces allows to circumvent this difficulty. This picture will applied to the quantization of GRT and one could see the resulting theory as a guess for what GRT limit of TGD could be. The first guess that Kähler function corresponds to Einstein-Maxwell action for this kind of preferred extremal turns out to be correct. An essential and radically new element of TGD is the possibility of space-time regions with Euclidian signature of the induced metric replacing the interiors of blackholes: this element will be assumed also now. The conditions that CP_2 represents and extremal of EYM action requires cosmological constant in Euclidian regions determined by the constant curvature of CP_2 and one can ask whether the average value of cosmological constant over 3-space could correspond to the cosmological constant explaining accelerating cosmic expansion.

4. Before going to a more precise formulation it is better to discuss how the phenomenology of EG with gravitons and without the fuzzy assumption about the emergence of space-time could be understood in TGD framework. This article is kind of continuation to the earlier article published in http://www.scribd.com/doc/45928480/PSTJ-V1-10-More-Possible-Games-in-Town-ContinuedPrespace-Time Journal [22], where the proposal that Quantum TGD as a hermitian square root of thermodynamics might imply something analogous to entropic gravity since S-matrix is replaced with the analog of thermal S-matrix. The article of Hossenfelder [19] has been of great help. Entropic gravity is generalized in TGD framework so that all interactions are entropic: the reason is that in zero energy ontology (ZEO) the $S-$matrix is replaced with $M-$matrix defining a square root of thermodynamics in a well defined sense.

2 The phenomenology of EG in TGD framework

In TGD framework one can consider a modification of EG allowing gravitons. In this framework thermodynamics is assigned with the virtual gravitons (and also real ones) flowing along the flux tubes mediating gravitational interaction. The entropy proportional to the length of flux tube corresponds to the entropy assigned with the holographic screen and temperature is the temperature of gravitons decreasing with distance just like the temperature of the radiation from Sun decreases as $1/r^2$: this is due to the absence of gravitonic heat sources in empty space.

TGD based view about EG leads also to new views. The basic objection against EG is that it applies also to electromagnetic interactions and leads to negative temperatures [19]. In zero energy ontology the resolution of the problem could be that matter and antimatter correspond to opposite arrow sof geometric time and therefore different causal diamonds and space-time sheets: this could explain also the apparent absence of antimatter.

2.1 EG with gravitons and without emergence of space-time

The following arguments explain how the basic formulas of EG follow from TGD framework assuming that virtual gravitons reside at flux tubes connecting interacting systems.

1. The argument originally to Kobakhidze [20] suggests that EG in the strong sense predicting the absence of gravitons is inconsistent with experimental facts. The argument does not mention gravitons but relies on the experimental fact that neutron bound states in Earth's gravitational field exist. Chaichian et al [21] however claim the argument contains an error because the formula (8) of [20] for the density matrix of neutron plus screen reading as

$$\rho_S(z + \Delta z) = \rho_N(z + \Delta z) \times \rho_{S/N}(z)$$

gives constant density matrix for screen when one removes neutron and this is certainly not true. According to Kobakhidze (private communication) the theory of Verlinde implies that the removal of neutron effectively removes the screen from $z + \Delta z$ to z. I leave it for the reader to decide what is the truth. Second challengable assumption of Kobakhidze used before equation (10) of [20] is the additivity of the entropies of the screen and neutron: the interaction with the screen implies interaction entropy and the question is whether it can be neglected.

2. According to Chaichian et al [21] that there exist transitions between the excited states suggest that the emission of gravitons must be involved (one can of course consider also electromagnetic transitions). This assumption is not testable since the rate of graviton induced transitions is extremely low. This result together with the vision about quantum theory as a square root of thermodynamics suggests that one must consider a modification of EG such that it allows gravitons and try to assign entropy and temperature to some real systems.

3. Suppose that one takes EG formulas seriously but accepts the existence of gravitons. EG should be understandable in terms of the classical space-time correlates of gravitational interaction assignable to virtual gravitons with space-like momenta. Could virtual gravitons mediating the gravitational flux through a hologram surface be responsible for the gravitational entropy?

   Could one assign entropy to the gravitons inside flux tube like structures from the source and traversing the holographic screen and carrying virtual gravitons with wave length much shorter than the distance to source so that quantum coherence for gravitons is lost? If the density of entropy per unit length of the flux tube is constant, gravitational entropy is proportional to the length of flux tube from the source to the constant potential surface so that $S \propto \Phi_{gr} A$ hypothesis would follow as a consequence.

4. Why the temperature of graviton carrying flux tubes should be reduced as $1/r^2$ with distance in the case of a spherically symmetric source? Could the masses serve as heat sources creating thermal ensemble of gravitons? The virtual gravitons emitted at the source would be at certain temperature just as ordinary photons created in Sun. The gravitons flowing along the flux tubes would cool- maybe by the expansion of the transversal cross section of the flux tube- and the condition that heat is not created or absorbed in the empty space would imply $1/r^2$ behavior. The flux tubes carrying virtual gravitons would serve as counterparts of long strings in holographic argument. In TGD the string like objects indeed appear quite concretely.

5. By using reduced mass, gravitational temperature and entropy become symmetric as functions of the masses of two objects. This assumption makes sense only in many-sheeted space-time for which each pair of systems is characterized by its own flux tubes (space-time sheets) mediating the gravitational interaction. Also the notion of gravitational Planck constant proportional to GMm makes sense only if it characterizes the flux tubes.

6. Unless the special nature of gravitational force as inertial force distinguishes gravitation from other interactions representing genuine forces, EG argument applies also in electrodynamics. The temperature in this case is proportional to the projection of the electric field which is in the direction of the normal of constant potential surface and has wrong sign for the second sign of the charge. Could the negative temperature implying instability relating somehow to the matter antimatter asymmetry? Antimatter and antimatter could not appear in same space-time region because either of them would give rise to negative temperature for flux tubes carrying virtual photons. In TGD framework similar outcome results also from totally different arguments and states that matter and antimatter should reside at different space-time sheets. Antimatter could be also dark in TGD sense. This point will be discussed in detail below and will be related

to the generation of thermodynamical arrow of time which would be different for particles and antiparticles. In this case the reduced mass must be replaced with reduced charge $Q_1Q_2/(Q_+Q_2)$ to achieve symmetry.

7. Could one say that in the GRANIT experiment [18] giving support for the description of the neutron in Earth's gravitational field using Schrödinger equation the entropy of neutron plus screen is just the entropy associated with the Coulomb potential of Earth and neutron obtainable as $S(r) \propto (\phi_{gr,Earth} + \Phi_{gr,neutron})A$? The gravitational potential appearing in the Schrödinger equation would be expressible essentially as the entropy per surface area and -as already noticed- this could be a mere accident having nothing to do with the real nature of gravitational force.

The assignment of entropy with the lines of generalized Feynman graphs is consistent with the replacement of S-matrix with $M-$matrix identified as a product of S-matrix and a Hermitian square root of density matrix commuting with $S-$matrix. These Hermitian square roots commute with $S-$matrix and generate infinite-D symmetry algebra of $S-$matrix defining a generalization of Yangian in ZEO since they are multi-local with respect to the partonic 2-surfaces located at the two light-like boundaries of CD. This algebra generated by zero energy states generalizes the twistorial Yangian and allowing CDs with integer multiples of basic scale one obtains a generalization of Kac-Moody algebra in which the non-commutative phase S^n generalizes the commutative phase factor $exp(in\phi)$ of Kac-Moody algebra.

2.2 Could gravity reduce to entropic force in long length scales?

The pessimistic view is that the possibility to regard gravitation as an entropic force is purely accidental and follows from the fact that gravitational potential happens to represent the density of gravitonic entropy per surface area and gravitonic temperature happens to be proportional to the normal component of the gravitational acceleration. On the other hand, one can develop an argument in which the absorption l of virtual gravitons with wavelength must shorter than the distance between the two systems is analogous to radiation pressure and describable in terms of entropic gravity.

The proposal that both virtual and real gravitons are characterized by temperature and entropy is questionable in standard quantum theory. It however makes sense in ZEO in which $S-$matrix is replaced with $M-$matrix identifiable as a Hermitian square root of density matrix so that thermodynamics emerges even at the level of virtual particles. That it does so conforms with the fact that the basic building blocks of virtual particles are on mass shell massless particles. Allowing negative energies one can have also space-like net values of virtual momenta and virtual particles differ from incoming ones only in that the bound state conditions for masses is given up. The resulting powerful constraints on virtual momenta allowing to avoid both UV and IR divergences and justify twistorial description for both on mass shell particles and virtual particles.

2.3 Flux tube picture for gravitational interaction

Consider now the emission of gravitational radiation and its absorpion allowing also virtual gravitons. In the picture about flux tubes as space-time sheets carrying gravitons between two objects there are two cases as I have discussed earlier but without realizing that these cases could correspond to to non-entropic and entropic gravitation respectively.

Remark: The flux tube picture emerged from the attempt to understand why the gravitational Planck constant introduced by Nottale and taken seriously by me as characteristics of dark gravitons is proportional to the masses of Sun and planet: the explanation is that $\hbar_{gr}$ is associated with flux tubes connecting these objects. It follows also from fractal string picture with string like objects identified as flux tubes.

In the minimal formulation the hierarchy of Planck constants coming as integer multiples of ordinary Planck constant and assigned to dark matter can be understood as an effective hierarchy due to the possibility of many-sheeted classical solutions of field equations with identical canonical momentum densities at various sheets implied by the huge vacuum degeneracy of Kähler action.

1. When the wavelength of gravitons is longer than that of flux tube, the graviton serves as a string connecting the systems (say ends of long bar, of the receiving system and source-not in practice) together and induces at classical level coherent oscillations of the relative distance.

In the detection of gravitational waves this kind arrangement should appear and typically appears. For instance, for millisecond pulsar the graviton wavelength is about 10^5 meters. This would represent quantum realm in which entropic gravity does not apply. Classical description however works in accordance with quantum classical correspondence.

Remark: If one is ready to take seriously the idea about large gravitational Planck constant, the wavelengths would be very long and one would be practically always in this realm.

2. When the wave length of gravitons is shorter than flux tube, the graviton beam losses its coherence and is characterized by temperature and entropy and generates on the receiver something analogous to gravitational radiation pressure induced by virtual particles (this pressure is however negative for gravitation!). This would generate entropic force with definite direction since the momentum of virtual gravitons is of the same sign.

   (a) This would suggest that gravitational waves with wavelengths shorter than the size of the detector should not be detectable via standard empirical arrangements.

   (b) A stronger condition would be that gravitational waves with wave lengths shorter than the distance between source and receiver cannot be detected: this would effectively conform with EG and predict that gravitational waves ill not be detected. This should have no practical consequences since even in the case of neutrons of GRANIT experiment the wavelength seems to be of order 10^5 meters from the peV energy scale of the bound states in Earth's gravitational field.

3. Entropic gravity is not in conflict with the geometrization of gravitational interaction since also thermodynamics should have space-time correlates by quantum classical correspondence. In accordance with stringy vision about short range gravitation, gravitational interaction in non-entropic realm is mediated by flux tubes connecting the masses involved and acting like strings.

2.4 The identification of the temperature and entropy

One can look at the situation also at more quantitative level. The natural guess for the temperature parameter would be as Unruh temperature

$$T_{gr} = \frac{\hbar}{2\pi}a \ , \tag{2.1}$$

where a is the projection of the gravitational acceleration along the normal of the gravitational potential = constant surface. In the Newtonian limit it would be acceleration associated with the relative coordinates and correspond to the reduced mass and equal to $a = G(m_1 + m_2)/r^2$.

One could identify T_{gr} also as the magnitude of gravitational acceleration. In this case the definition would involved only be purely local. This is in accordance with the character of temperature as intensive property.

The general relativistic objection against the generalization is that gravitation is not a genuine force: only a genuine acceleration due to other interactions than gravity should contribute to the Unruh temperature so that gravitonic Unruh temperature should vanish. On the other hand, any genuine force should give rise to an acceleration. The sign of the temperature parameter would be different for attractive and repulsive forces so that negative temperatures would become possible. Also the lack of general coordinate invariance is a heavy objection against the formula.

2.4.1 Gravitonic temperature in TGD Universe

In TGD Universe the situation is different. In this case the definition of temperature as magnitude of local acceleration is more natural.

1. Space-time surface is sub-manifold of the imbedding space and one can talk about acceleration of a point like particle in imbedding space $M^4 \times CP_2$. This acceleration corresponds to the trace of the second fundamental form for the imbedding and is completely well-defined and

general coordinate invariant quantity and vanishes for the geodesics of the imbedding space. Since acceleration is a purely geometric quantity this temperature would be same for flux sheets irrespective of whether they mediate gravitational or some other interactions so that all kinds of virtual particles would be characterized by this same temperature.

2. One could even generalize T_{gr} to a purely local position dependent parameter by identifying it as the magnitude of second fundamental form at given point of space-time surface. This would mean that the temperature in question would have purely geometric correlate. This temperature would be alwas non-negative. This purely local definition would also save from possible inconsistencies in the definition of temperature resulting from the assumption that its sign depends on whether the interaction is repulsive or attractive.

3. The trace of the second fundamental form -call it H- and thus T_{gr} vanishes for minimal surfaces. Examples of minimal surfaces are cosmic strings [9], massless extremals, and CP_2 type vacuum extremals with $M4$ projection which is light-like geodesic [7]. Vacuum extremals with at most 2-D Lagrangian CP_2 projection has a non-vanishing H and this is true also for their deformations defining the counterpart of GRT space-time. Also the deformations of cosmic strings with 2-D M^4 projection to magnetic flux tubes with 4-D M^4 projection are expected to be non-minimal surfaces. Same applies to the deformations of CP_2 vacuum extremals near the region where the signature of the induced metric changes. The predicted cosmic string dominated phase of primordial cosmology [10] would correspond to the vanishing gravitonic temperature. I have not been able to construct any explicit examples about the non-vacuum extremals with non-vanishing H but physical intuition strongly supports their existence. Also generic CP_2 type vacuum extremalshas non-vanishing H.

4. Massless extremals define an excellent macroscopic space-time correlate for gravitons. The massivation of gravitons is however strongly suggested by simple considerations encouraged by twistorial picture and wormhole throats connecting parallel MEs define the basic building bricks of gravitons and would bring in non-vanishing geometric temperature, (extremely small but non-vanishing) graviton mass, and gravitonic entropy.

   (a) The M^4 projection of CP_2 type vacuum extremal is random light-like curve rather than geodesic of M^4 (this gives rise to Virasoro conditions [7]). The mass scale defined by the second fundamental form describing acceleration is non-vanishing. I have indeed assigned this scale as well as the mixing of M^4 and CP_2 gamma matrices inducing mixing of M^4 chiralities to massivation. The original proposal was that the trace of second fundamental form could be identifiable as classical counterpart of Higgs field. One can speak of light-like randomness above a given length scale defined by the inverse of the length of the acceleration vector.

   (b) This suggests a connection with p-adic mass calculations: the p-adic mass scale m_p is proportional to the acceleration and thus could be given by the geometric temperature: $m_p = nR^{-1}p^{-1/2} \sim \hbar H = \hbar a$, where $R \sim 10^4 L_{Pl}$ is CP_2 radius, and n some numerical constant of order unity. This would determine the mass scale of the particle and relate it to the momentum exchange along corresponding CP_2 type vacuum extremal. Local graviton mass scale at the flux tubes mediating gravitational interaction would be essentially the geometric temperature.

   (c) Interestingly, for photons at the flux tubes mediating Coulomb interactions in hydrogen atom this mass scale would be of order $\hbar a \sim e^2\hbar/m_p n^4 a_0^2 \sim 10^{-5}/n^4$ eV, which is of same order of magnitude as Lamb shift, which corresponds to 10^{-6} eV energy scale for $n = 2$ level of hydrogen atom. Hence it might be possible to kill the hypothesis rather easily.

   (d) Note that momentum exchange is space-like for Coulomb interaction and the trace H^k of second fundamental form would be space-like vector. It seems that one define mass scale as $H = \sqrt{-H^k H_k}$ to get a real quantity.

   (e) This picture is in line with the view that also the bosons usually regarded as massless possess a small mass serving as an IR cufoff. This vision is inspired by zero energy ontology and twistorial considerations [13]. The prediction that Higgs is completely eaten by gauge bosons in massivation is a prediction perhaps testable at LHC already during year 2011.

Remark: In MOND theory of dark matter a critical value of acceleration is introduced. I do not believe personally to MOND and TGD explains galactic rotation curves without any modification of Newtonian dynamics in terms of dark matter assignable to cosmic strings containing galaxies like around it like pearls in necklace. In TGD framework the critical acceleration would be the acceleration above which the gravitational acceleration caused by the dark matter associated with the cosmic strings traversing along galactic plane orthogonally and behaving as $1/\rho$ overcomes the acceleration caused by the galactic matter and behaving as $1/\rho^2$. Could this critical acceleration correspond to a critical temperature T_{gr}- presumably determined by an appropriate p-adic length scale and coming as a power $2^{-k/2}$ by p-adic length scale hypothesis? Could critical value of H perhaps characterize also a critical magnitude for the deformation from minimal surface extremal? The critical acceleration in Milgrom's model is about 1.2×10^{-10} m/s^2 and corresponds to a time scale of 10^{12} years, which is of the order of the age of the Universe.

The formula contains Planck constant and the obvious question of the inhabitant of TGD Universe is whether the Planck constant can be identified with the ordinary Planck constant or with the *effective* Planck constant coming as integer multiple of it [14].

1. For the ordinary value of $\hbar$ the gravitational Unruh temperature is extremely small. To make things more concrete one can express the Unruh temperature in gravitational case in terms of Schwartschild radius $r_S = 2GMm$ at Newtonian limit. This gives

$$T_{gr} = \frac{\hbar}{4\pi r_S}\frac{M+m}{M}(\frac{r_S}{r})^2 \quad . \tag{2.2}$$

   Even at Schwartschild radius the temperature corresponds to Compton length of order $4\pi r_S$ for $m << M$.

2. Suppose that Planck constant is gravitational Planck constant $\hbar_{gr} = GMm/v_0$, where $v_0 \simeq 2^{-11}$ holds true for inner planets in solar system [11]. This would give

$$T_{gr} = \frac{m}{8\pi v_0}\frac{M+m}{M}(\frac{r_S}{r})^2 \quad .$$

   The value is gigantic so that one must assume that the temperature parameter corresponds to the minimum value of Planck constant. This conforms with the identification of the p-adic mass scale in terms of the geometric temperature.

2.4.2 Gravitonic entropy in TGD Universe

A good guess for the value of gravitational entropy (gravitonic entropy associated with the flux tube mediating gravitational interaction) comes from the observation that it should be proportional to the flux tube length.The relationship $dE = TdS$ suggests $S \propto \phi_{gr}/T_{gr}$ as the first guess in Newtonian limit. A better guess would be

$$S_{gr} = -\frac{V_{gr}}{T_{gr}} = \frac{M+m}{M}\frac{(r}{\hbar m}, \quad , \tag{2.3}$$

The replacement $M \to M+m$ appearing in the Newtonian equations of motion for the reduced mass has been performed to obtain symmetry with respect to the exchange of the masses.

The entropy would depend on the interaction mediated by the space-time sheet in question which suggests that the generalization is

$$S = -\frac{V(r)}{T_{gr}} \quad . \tag{2.4}$$

Here $V(r)$ is the potential energy of the interaction. The sign of S depends on whether the interaction is attractive or repulsive and also on the sign of the temperature. For a repulsive interaction the entropy would be negative so that the state would be thermodynamically unstable in ordinary thermodynamics.

The integration of $dE = TdS$ in the case of Coulomb potential gives $E = V(r) - V(0)$ for both options. If the charge density near origin is constant, one has $V(r) \propto r^2$ in this region implying $V(0) = 0$ so that one obtains Coulombic interaction energy $E = V(r)$. Hence thermodynamical interpretation makes sense formally.

The challenge is to generalize the formula of entropy in Lorentz invariant and general coordinate invariant manner. Basically the challenge is to express the interaction energy in this manner. Entropy characterizes the entire flux tube and is therefore a non-local quantity. This justifies the use of interaction energy in the formula. In principle the dynamics defined by the extremals of Kähler action predicts the dependence of the interaction energy on Minkowskian length of the flux tube, which is well-defined in TGD Universe. Entropy should be also a scalar. This is achieved since the rest frame is fixed uniquely by the time direction defined by the time-like line connecting the tips of CD: the interaction energy in rest frame of CD defines a scalar. Note that the sign of entropy correlates with the sign of interaction energy so that the repulsive situation would be thermodynamically unstable and this indeed suggests that antimatter should have opposite arrow of time.

The sign of entropy for a Coulomb type interaction potential is always positive for the identification of T_{gr} as the normal component of gravitational acceleration whereas T_{gr} can be negative. If T_{gr} corresponds to the magnitude of the acceleration, entropy is negative for repulsive Coulomb interaction.

2.5 Negative temperatures/entropies for virtual bosons and the spontaneous generation of the arrow of time in ZEO

Negative entropies/temperatures are especially interesting from the point of ZEO in which causal diamonds (CDs) containing positive and negative energy states at their future and past light-like boundaries. Note that the term CD is used somewhat loosely about Cartesian product of CD and CP_2. Note also that CD is highly analogous to Penrose diagram and defines causal unit in quantum TGD.

There is also a fractal hierarchy CDs within CDs and the minimum number theoretically motivated assumption is that the scales of CDs come as integer multiples of CP_2 scale. Poincare transforms of CDs with respect to another tip are allowed and the position of the second tip with respect to the first one is quantized for number theoretic reasons and corresponds to a lattice like structure in the proper time constant hyperboloid of M^4_+. This has some highly non-trivial cosmological implications such as quantization of cosmic redshifts for which there is empirical evidence.

Both definitions lead to very similar predictions.

1. The identification of temperature T_{gr} as a scalar defined by the length of second fundamental form is favored in TGD framework. Entropy is defined in terms of interaction energy by the formula $S = -V/T_{gr}$. This definition can be defended in TGD Universe by Poincare invariance and general coordinate invariance. In this case temperature is always non-negative and entropy is positive for attractive interactions but negative for repulsive interactions. Therefore systems consisting mostly from matter or antimatter and having repulsive electromagnetic Coulomb forces have negative entropy and should be thermodynamically unstable. This would suggest that the arrow of time for these systems could be non-standard one in ZEO. For charge neutral systems entropy can be positive. It does not matter whether the system consists of matter or antimatter.

2. Second definition differs from the first one only in that T_{gr} is the magnitude of acceleration with a sign factor telling whether repulsion or attraction is in question. In this temperature can have both signs but entropy is always non-negative. For systems consisting dominantly of matter or antimatter with long range Coulomb interactions the temperature would be negative but entropy positive. This would suggest that the arrow of geometric time is non-standard one. Again it does not matter whether the system consists of matter or antimatter.

The obvious idea is that the thermal instability could imply matter antimatter asymmetry. The original argument that antimatter and matter would correspond to opposite arrows of geometric time turned out to be wrong. One can however modify the argument to state that thermal instability leads to a generation of regions consisting preferentially of matter and antimatter and having non-standard arrow of geometric time so that from the point of view of standard arrow of geometric time these region are formed rather than decay as second law would dictate. For definiteness the definition of geometric temperature as trace of the second fundamental form is assumed but the argument can be easily modified to the second case.

1. Does the negative entropy mean that the time evolutions assignable to the systems consisting mostly of matter (or antimatter) obeys opposite arrow of geometric time? From the point of view of observer with standard arrow of time these systems would obey second law in reverse direction of the geometric time. Spontaneous self assembly of biomolecules representes a standard example about this and the interpretation would be in terms of formation of structures consisting preferentially of matter or antimatter. Could this lead to a separation of antimatter to separate domains in the final states identifiable as negative energy parts of zero energy states? If so then matter matter antimatter asymmetry would relate to the purely geometric thermodynamics.

2. The arrow of geometric time emerges spontaneously in TGD Universe by a not too well-understood mechanism involving arguments from TGD inspired theory of consciousness. Thermodynamics must be involved since the sequence of quantum jumps identified as moments of consciousness induces the arrow of experienced time. Could it be that the arrow of geometric time is opposite for charged particles and antiparticles from thermodynamic stability?

   (a) Quite generally, positive energy parts of at past boundary of CD energy states would have definite particle number and also other quantum numbers whereas the outcome of measurement at future boundary dictated by $M-$matrix would be a superposition of final states at the opposite end of CD. This defines the arrow of geometric time as the direction of geometric time induced by that of thermodynamical time and experienced time defined in terms of a sequence of quantum jumps.

   (b) What mechanism selects the light-like boundary of CD which corresponds to the initial prepared states with second one identified in terms of the outcome of the scattering process expressible as a superpositions of states with well defined particle numbers and also other quantum numbers? The mechanism should relate to the square root of density matrix appearing in $M-$matrix and therefore to entropy of virtual bosons consisting of basic building blocks which are on mass shell massless particles with both signs of energy assignable to what I call wormhole throats to be discussed below.

   (c) The wrong sign of the entropy for systems consisting predominantly of matter or antimatter means they have must have negative energies and second law realized as properties of zero energy states would correspond to opposite direction of geometric time allowed in TGD based generalization of thermodynamics. The arrow would emerge at scales longer than wavelength and would be therefore a macroscopic phenomenon if wavelength is taken as the borderline between microscopic and macroscopic.

2.6 How to circumvent the difficulties in generalizing EG to relativistic situation?

One argument against EG is that it applies as such to Newtonian gravity only. The general coordinate invariant and Lorentz invariant definitions of T and S have been already considered and are favore in TGD framework and give always non-negative temperature depending only on purely local data. In the following the original definitions of T and S involving equi-potential surfaces in the case of T are considered.

To make the generalization in a coordinate invariant manner two physically preferred coordinates defined modulo diffeomorphism are required: time coordinate t allowing to identify gravitational scalar potential Φ_{gr} as the deviation of g_{tt} from unity and radial coordinate orthogonal to the equipotential surfaces of Φ_{gr} so that Φ_{gr} itself could be regarded as the second preferred coordinate. This requires a slicing of space-time by 2-dimensional surfaces parametrized by (t,r) with remaining space-time coordinates regarded as constant for a given slice. The other two coordinates could define a dual slicing.

Entropy density $s_{gr} = dS_{gr}/dA$ per unit are of flux tube would be proportional to Φ_{gr} and a unique physical identification of the radial coordinate would be as proportional to the entropy

$S_{gr}(r) = \int s_{gr} dA \propto \int \Phi_{gr} dA$ proportional to radial coordinate in the Newtonian limit. One should somehow specify what one precisely means with flux tube and here the area could be identified as the area inside which Kähler magnetic flux has definite sign if monopole flux is involved. If not then Kähler flux could take this role.

A possible identification of the preferred coordinates (t, r) is in terms of stringy slicing of the space-time surface by 2-D surfaces required by general consistency conditions. Strings would connect the points of partonic 2-surfaces carrying fermion number and the braids defining the orbits of these points would define string world sheets so that a rather concrete concretization of TGD as almost topological QFT would be obtained.

The physical interpretation of stringy slicing is in terms of integrable distribution of planes of non-physical polarization directions assignable to massless fields and orthogonal dual slicing would correspond to the directions of physical polarizations. The existence of the stringy slicing is motivated also by number theoretical considerations. The general ansatz for the preferred extremals leads to an identification of time preferred coordinate as a coordinate associated with the flow lines of conserved currents defining Beltrami flow. Second stringy coordinate could correspond to the direction for the gradient of gravitational field $\Phi_{gr} = g_{tt} - 1$ in accordance with the idea that gravitons flow along string like flux tubes and the polarizations of gravitons are orthogonal to the direction of their motion.

The translation of Witten's ideas about knots to TGD framework lead to the string worlds sheets could correspond to inverse images of geodesic spheres of CP_2 for the imbedding map of space-time surface to CP_2. This would conform with the idea that wormhole throats are magnetic monopoles at the ends of stringy flux tubes.

3 The conceptual framework of TGD

There are several reasons to expect that something analogous to thermodynamics results from quantum TGD. The following summarizes the basic picture, which will be applied to a proposal about how to quantize (or rather de-quantize!) Einstein-Maxwell system with quantum states identified as the modes of classical WCW spinor field with spinors identifiable in terms of Clifford algebra of WCW generated by second quantized induced spinor fields of H.

1. In TGD framework quantum theory can be regarded as a "complex square root" of thermodynamics in the sense that zero energy states can be described in terms of what I call $M-$matrices which are products of hermitian square roots of density matrices and unitary $S-$matrix so that the moduli squared gives rise to a density matrix. The mutually orthogonal Hermitian square roots of density matrices span a Lie algebra of a subgroup of the unitary group and the $M-$matrices define a Kac-Moody type algebra with generators proportional to powers of S assuming that they commute with S. Therefore this algebra acts as symmetries of the theory.

   What is nice that this algebra consists of generators multi-local with respect to partonic 2-surfaces and represents therefore a generalization of Yangian algebra. The algebra of $M-$matrices makes sense if causal diamonds (double light-cones) have sizes coming as integer multiples of CP2 size. $U-$matrix has as its rows the $M-$matrices. One can look how much of this structure could make sense in GRT framework.

2. In TGD framework one is forced to geometrize WCW [5] consisting of 3-surfaces to which one can assign a unique space-time surfaces as analogs of Bohr orbits and identified as preferred extremals of Kähler action (Maxwell action essentially). The 3-surfaces could be identified as the intersections space-time surface with the future and past light-like boundaries causal diamond (CDs analogous to Penrose diagrams). The preferred extremals associated with the preferred 3-surfaces allow to realize General Coordinate Invariance (GCI) and its natural to assign quantum states with these.

   GCI in strong sense implies even stronger form of holography. Space-time regions with Euclidian signature of metric are unavoidable in TGD framework and have interpretation as particle like structure and are identified as lines of generalized Feynman diagrams. The light-like 3-surfaces at which the signature of the induced metric changes define equally good candidates for 3-surfaces with which to assign quantum numbers. If one accepts both identifications then the intersections of the ends of space-time surfaces with these light-like surfaces should code for physics. In other words, partonic 2-surfaces plus their 4-D tangent space-data would be enough and holography would be more or less what the holography of ordinary visual perception is!

In the sequel the 3-surfaces at the ends of space-time and and light-like 3-surfaces with degenerate 4-metric will be referred to as *preferred 3-surfaces*.

3. WCW spinor fields are proportional to a real exponent of Kähler function of WCW defined as Kähler action for a preferred extremal so that one has indeed square root of thermodynamics also in this sense with Kähler essential one half of Hamiltonian and Kähler coupling strength playing the role of dimensionless temperature in "vibrational" degrees of freedom. One should be able to identify the counterpart of Kähler function also in General Relativity and if one has Einstein-Maxwell system one could hope that the Kähler function is just the Maxwell action for a preferred extremal and therefore formally identical with the Kähler function in TGD framework.

   Fermionic degrees of freedom correspond to spinor degrees of freedom and are representable in terms of oscillator operators for second quantized induced spinor fields [4]. This means geometrization of fermionic statistics. There is no quantization at WCW level and everything is classical so that one has "quantum without quantum" as far as quantum states are considered.

4. The dynamics of the theory must be consistent with holography. This means that the Kähler action for preferred extremal must reduce to an integral over 3-surface. Kähler action density decomposes to a sum of two terms. The first term is $j^\alpha A_\alpha$ and second term a boundary term reducing to integral over light-like 3-surfaces and ends of the space-time surface. The first term must vanish and this is achieved if the Kähler current j^α is proportional to Abelian instanton current

$$j^\alpha \propto *j^\alpha = \epsilon^{\alpha\beta\gamma\delta} A_\beta J_{\gamma\delta} \tag{3.1}$$

   since the contraction involves A_α twice. This is at least part of the definition of preferred extremal property but not quite enough. Note that in Einstein-Maxwell system without matter j^α vanishes identically so that the action reduces automatically to a surface term.

5. The action would reduce reduce to terms which should make sense at light-like 3-surfaces. This means that only Abelian Chern-Simons term is allowed. This is guaranteed if the weak form of electric-magnetic duality [4] stating

$$* F^{n\beta} = kF^{n\beta} \tag{3.2}$$

   at preferred at light-like throats with degenerate four-metric and at the ends of space-time surface. These conditions reduce the action to Chern-Simons action with a constraint term realizing what I call weak form of electric-magnetic duality. One obtains almost topological QFT since the constraint term depends on metric. This is of course what one wants.

   Here the constant k is integer multiple of basic value which is proportional to g_K^2 from the quantization of Kähler electric charge which corresponds to U(1) part of electromagnetic charge. Fractional charges for quarks require $k = ng_K^2/3$. Physical particles correspond to several Kähler magnetically charged wormhole throats with vanishing net magnetic charge but with non-vanishing Kähler electric proportional to the sum $\sum_i \epsilon_i k_i Q_{m,i}$, with $\epsilon_i = \pm 1$ determined by the direction of the normal component of the magnetic flux for i:th throat.

   The first guess is that the length of magnetic flux tube associated with the particle is of order Compton length or perhaps corresponds to weak length scale as was the original proposal. The screening of weak isospin can be understood as magnetic confinement such that neutrino pair at the second end of magnetic flux tube screens the weak charged leaving only electromagnetic charge. Also color confinement could be understood in terms of flux tubes of length of order hadronic size scales. Compton length hypothesis is enough to understand color confinement and weak screening.

Note that $1/g_K^2$ factor in Kähler action is compensated by the proportionality of Chern-Simons action to g_K^2. This need not mean the absence of non-perturbative effects coming as powers of $1/g_K^2$ since the constraint expressing electric magnetic duality depends on g_K^2 and might introduce non-analytic dependence on g_K^2.

6. In TGD the space-like regions replace black holes and a concrete model for them is as deformations of CP_2 type vacuum extremals which are just warped imbeddings of CP_2 to $M^4 \times CP_2$ with random light-like random curve as M^4 projection: the light-like randomness gives Virasoro conditions. This reflects as a special case the conformal symmetries of light-like 3-surfaces and those assignable to the light-like ends of the CDs.

One could hope that this picture more or less applies for the GRT limit of quantum TGD.

4 What one obtains from quantum TGD by replacing space-times as surfaces with abstract 4-geometries?

It is interesting to see what one obtains when one applies TGD picture by replacing space-times as 4-surfaces with abstract geometries as in Einstein's theory and assumes holography in the sense that space-times satisfy besides Einstein-Maxwell equations also conditions guaranteeing Bohr orbit like property. The resulting picture could be also regarded as GRT type limit of quantum TGD obtained by dropping the condition that space-times are surfaces.

GRT is a more general theory than TGD in the sense that much more general space-times are allowed than in TGD - this leads also to difficulties - and one could also argue that the mathematical existence of WCW Kähler geometry actually forces the restriction of these geometries to those imbeddable in $M^4 \times CP_2$ so that the quantization of GRT type theory would lead to TGD.

4.1 What one wants?

What one wants is at least following.

1. Euclidian regions of the space-time should reduce to metrically deformed pieces of CP_2. Since CP_2 spinor structure does not exist without the coupling of the spinors to Kähler gauge potential of CP_2 one must have Maxwell field. CP_2 is gravitational instanton and constant curvature space so that cosmological constant is non-vanishing unless one adds a constant term to the Maxwell action, which is non-vanishing only in Euclidian regions. It is matter of taste, whether one regards V_0 as term in Maxwell action or as cosmological constant term in gravitational part of the action. CP_2 radius is determined by the value of this term so that it would define a fundamental constant.

   This raises an interesting question. Could one say that one has a small value of cosmological constant defined as the average value of cosmological constant assignable to the Euclidian regions of space-time? The average value would be proportional to the fraction of 3-space populated by Euclidian regions (particles and possibly also macroscopic Euclidian regions). The value of cosmological constant would be positive as is the observed value. In TGD framework the proposed explanation for the apparent cosmological constant is different but one must remain open minded. In fact, I have proposed the description in terms of cosmological constant also as a proper description in the approximation to TGD provided by GRT like theory. The answer to the question is far from obvious since the cosmological constant is associated with Euclidian rather than Minkowskian regions: all depends on the boundary conditions at the wormhole throats where the signature of the metric changes.

2. One can also consider the addition of Higgs term to the action in the hope that this could allow to get rid of constant term which is non-vanishing only in Euclidian regions. It turns turns out that only free action for Higgs field is possible from the condition that the sum of Higgs action and curvature scalar reduces to a surface term and that one must also now add to the action the constant term in Euclidian regions. Conformal invariance requires that Higgs is massless.

   The conceptual problem is that the surface term from Higgs does not correspond to topological action since it is expressible as as flux of $\Phi\nabla\Phi$. Hence the simplest possibility is that Kähler action contains a constant term in Euclidian regions just as in TGD, where curvature scalar is however absent. Einstein-Maxwell field equations however apply that it vanishes and is effectively absent also in GRT quantized like TGD.

3. Reissner-Nordström solutions are obtained as regions exterior to CP_2 type regions. In black hole horizons (when they exist) the 3- metric becomes light-like but 4-metric remains non-degenerate. Hence R-N solution cannot be directly glued to a deformed CP_2 type region at horizon but a transition region in which the determinant of 4-metric becomes zero must be present. The simplest possibility is that R-N metric is deformed slightly so that one has $g_{tt} = 0$ and $g_{rr} < \infty$ at the horizon. This surface would correspond to a wormhole throat in TGD framework. Most of the blackhole interior would be replaced with CP_2 type region. In TGD black hole solutions indeed fail to be imbeddable at certain radius so that deformed CP_2 type vacuum extremal is much more natural object than black hole. In the recent framework the finite size of CP_2 means that macroscopic size for the Euclidian regions requires large deformation of CP_2 type solution. For masses $M < Q/\sqrt{G}$ R-N metric has no horizons so that in the case of elementary particles the situation is more complex than this.

   Remark: In TGD framework large value of $\hbar$ and space-time as 4-surface property changes the situation. The generalization of Nottale's formula for gravitational Planck constant in the case of self gravitating system gives $\hbar_{gr} = GM^2/v_0$, where $v_0/c < 1$ has interpretation as velocity type parameter perhaps identifiable as a rotation velocity of matter in black hole horizon [11, 12]. This gives for the Compton length associated with mass M the value $L_C = \hbar_{gr}/M = GM/v_0$. For $v_0 = c/2$ one obtains Scwartschild radius as Compton length. The interpretation would be that one has CP_2 type vacuum extremal in the interior up to some macroscopic value of Minkowski distance. One can whether even the large voids containing galaxies at their boundaries could correspond to Euclidian blackhole like regions of space-time surface at the level of dark matter.

4. The geometry of CP_2 allows to understand standard model symmetries when one considers space-times as surfaces [6]. This is not necessarily the case for GRT limit.

   (a) In the recent case one has different situation color quantum numbers make sense only inside the Euclidian regions and momentum quantum numbers in Minkowskian regions. This is in conflict with the assumption that quarks can carry both momentum and color. On the other, color confinement could be used to argue that this is not a problem.

   (b) One could assume that spinors are actually 8-component $M^4 \times CP_2$ spinors but this would be somewhat ad hoc assumption in general relativistic context. Also the existence of this kind of spinor structure is not obvious for general solutions of Einstein-Maxwell equations unless one just assumes it.

   (c) It is far from clear whether the symplectic transformations of CP_2 could be interpreted as isometries of WCW in general relativity like theory [5, 3, 4]. These symmetries certainly act in non-trivial manner on Euclidian regions but it is highly questionable whether this could give rise to a genuine symmetry. Same applies to Kac-Moody symmetries assigned to isometries of $M^4 \times CP_2$ in TGD framework. These symmetries are absolutely essential for the existence of WCW Kähler geometry in infinite-D context as already the uniqueness of the loop space Kähler geometries demonstrates [17] (maximal group of isometries is required by the existence of Riemann connection).

   Note that a generalization of Equivalence Principle follows in TGD framework from the assumption that coset representations of super-conformal symplectic algebra and super Kac-Moody algebra define conformally invariant physical states. The equality of gravitational and inertial masses follows from the condition that the actions of the super-generators of two algebras are identical. This also justifies the use p-adic thermodynamics[1] for the scaling generator of either super-conformal algebra without a loss of conformal invariance.

5. One could argue that GRT limit does not make sense since in Minkowskian regions the theory knows nothing about the color and electroweak quantum numbers: there is only metric and Maxwell field. On the other hand, in TGD one has color confinement and weak screening by magnetic confinement. If the functional integral over Euclidian regions representing generalized Feynman diagrams is enough to construct scattering amplitudes, pure Einstein-Maxwell

system in Minkowskian regions might be enough. All experimental data is expressible in terms of classical em and gravitational fields. If Weinberg angle vanishes in Minkowskian regions, electromagnetic field reduces to Kähler form and the interpretation of the Maxwell field as em field should make sense. The very tight empirical constraints on the value of Kähler coupling strength α_K indeed allow its identification as fine structure constant at electron length scale.

6. One can worry about the almost total disappearance of the metric from the theory. This is not a problem in TGD framework since all elementary particles correspond to many-fermion states. For instance, gauge bosons are identified as pairs of fermion and antifermion associated with opposite throats of a wormhole connecting two space-time sheets with Minkowskian signature of the induced metric. Similar picture should make sense also now.

7. TGD possesses also approximate super-symmetries and one can argue that also these symmetries should be possessed by the GRT limit. All modes of induced spinor field generate a badly broken SUSY with rather large value of $\mathcal{N}$ (number of spinor modes) and right-handed neutrino and its antiparticle give rise to $\mathcal{N} = \in$ SUSY with R-parity breaking induced by the mixing of left- and right handed neutrinos induced by the modified Dirac equation. This picture is consistent with the existing data from LHC and there are characteristic signatures -such as the decay of super partner to partner and neutrino- allowing to test it. These super-symmetries might make sense if one replaces ordinary space-time spinors with 8-D spinors.

   Note that the possible inconsistency of Minkowskian and Euclidian 4-D spinor structures might force the use of 8-D Minkowskian spinor structure.

4.2 Basic properties of Reissner-Nordström metric

Denote the coordinates of M^4_+ by (m^0, r_M, θ, ϕ) and those of X^4 by (t, r_M, θ, ϕ). The expression for Reissner-Nordström metric reads as

$$\begin{aligned} ds^2 &= Adt^2 - Bdr_M^2 - r_M^2 d\Omega^2 \ , \\ A &= 1 - \frac{r_s}{r_M} + \frac{r_Q^2}{r_M^2} \ , \quad B = \frac{1}{A} \ , \\ r_s &= 2GM \ , \quad r_Q^2 = Q^2 G \ . \end{aligned} \tag{4.1}$$

Here the charge $Q^2 = g^2 q^2 = 4\pi\alpha\hbar q^2$ contains gauge coupling g for the Maxwell field. For Kähler field one would have $g = g_K$.

The metric has two horizons for large enough mass values corresponding to the vanishing of function A implying that the sphere at which the vanishing takes place becomes metrically effectively 2-dimensional light-like 3-surface analogous to the boundary of light-cone. Note however that the determinant of the 4-metric is non-vanishing but just the finiteness of the radial component of the metric (something rather natural) would make it vanishing if g_{tt} remains zero. The horizon radii are given by

$$r_\pm = \frac{r_s}{2}\left[1 \pm \sqrt{1 - (\frac{r_Q}{r_s})^2}\right] \ . \tag{4.2}$$

$r_\pm$ is real for

$$M \geq M_Q = \frac{Q}{\sqrt{G}} \ . \tag{4.3}$$

For smaller masses one has no horizons and naked singularity at origin. The imbeddability condition however implies that the imbedding fails below some critical radius.

Some general comments about the relation to TGD are in order [8].

1. Reissner-Nordström metric has imbedding as a vacuum extremal but not as non-vacuum extremal for which induced Kähler field would appear as Maxwell field. Vacuum extremals which are very important in TGD framework have no counterpart in Maxwell-Einstein system, which forces to question the assumption that Einstein-Maxwell system could serve as a GRT type limit of TGD except at macroscopic scales defined by the mass condition.

2. The solution is not expected to describe the exterior metric of objects with $M < M_Q$ at short distances. For elementary particles one expects different space-time correlates of gravitational interaction. One might optimistically guess that this is the realm where TGD replaces General Relativity.

3. The determinant of the four metric is non-vanishing at the horizons so that they cannot correspond to wormhole throats. There must be a transition region within which the determinant of the metric goes to zero at both Euclidian and Minkowskian region. The transition region could be around either horizon of the Reissner-Nordström metric when these exist. For elementary particles the situation is different since R-N metric has no horizon in this case. The critical mass corresponds to a condensed matter blob with size scale of living cell and one can ask whether it might be possible to test experimentally whether something happens in the transition region.

4. Non-vacuum extremals of Kähler action are relevant near wormhole throats and an interesting and the behavior of radially symmetric extremal of Kähler action with induced Kähler form defining the Maxwell field is still an open question. This kind of extremal would serve as the first guess for a model of the exterior space-time of elementary particle but could be quite too simple. In fact, the light-likeness of wormhole throats suggests a more complex zitterbegung like behavior so that stationarity and spherical symmetry would be quite too strong conditions on the metric.

It is interesting to apply the formula for the gravitational Planck constant [11] to the lower bound for M. The formula reads as

$$\hbar_{gr} = \frac{GMm}{v_0} , \quad \frac{v_0}{c} < 1 \ . \tag{4.4}$$

The parameter v_0 has dimensions of velocity and for the space-time sheets mediating gravitational interaction between Sun and the three inner planets one has $v_0 \simeq 2^{-11}$. By writing the expression for M_Q as $M_Q = q\sqrt{\alpha_K}\hbar_{gr}\sqrt{G}$, where α_K can be assumed to be equal to fine structure constant, one finds that horizons exist only if the condition

$$q \ \leq \ \frac{v_0}{\sqrt{G}m\sqrt{\alpha_K}} \ . \tag{4.5}$$

Therefore solar system would represent a genuine elementary particle like realm in which Reissner-Nordstöm like metric does not apply unless the electromagnetic charge is so small that it vanishes by its quantization, which is of course a non-realistic condition. This idealized argument suggests the smallness of the electric charge as a condition for the applicability of GRT type description and this indeed guarantees that space-time sheets are near vacuum extremals so that small deformation of Scwartschild metric should apply.

4.3 Reduction of the quantization of Kähler electric charge to that of electromagnetic charge

The best manner to learn more is to challenge the form of the weak electric-magnetic duality based on the induced Kähler form.

1. Physically it would seem more sensible to pose the duality on electromagnetic charge rather than Kähler charge. This would replace induced Kähler form with electromagnetic field, which is a linear combination of induced K"ahler field and classical Z^0 field

$$\begin{aligned} \gamma &= 3J - sin^2\theta_W R_{03} \ , \\ Z^0 &= 2R_{03} \ . \end{aligned} \tag{4.6}$$

Here $Z_0 = 2R_{03}$ is the appropriate component of CP_2 curvature form [2]. For a vanishing Weinberg angle the condition reduces to that for Kähler form.

2. For the Euclidian space-time regions having interpretation as lines of generalized Feynman diagrams Weinberg angle should be non-vanishing. In Minkowskian regions Weinberg angle could however vanish. If so, the condition guaranteing that electromagnetic charge of the partonic 2-surfaces equals to the above condition stating that the em charge assignable to the fermion content of the partonic 2-surfaces reduces to the classical Kähler electric flux at the Minkowskian side of the wormhole throat. One can argue that Weinberg angle must increase smoothly from a vanishing value at both sides of wormhole throat to its value in the deep interior of the Euclidian region.

3. The vanishing of the Weinberg angle in Minkowskian regions conforms with the physical intuition. Above elementary particle length scales one sees only the classical electric field reducing to the induced Kähler form and classical Z^0 fields and color gauge fields are effectively absent. Only in phases with a large value of Planck constant classical Z^0 field and other classical weak fields and color gauge field could make themselves visible. Cell membrane could be one such system [16, 15]. This conforms with the general picture about color confinement and weak massivation.

The GRT limit of TGD suggests a further reason for why Weinberg angle should vanish in Minkowskian regions.

1. The value of the Kähler coupling strength mut be very near to the value of the fine structure constant in electron length scale and these constants can be assumed to be equal.

2. Einstein-Maxwell limit would make sense only for a vanishing Weinberg angle in Minkowskian regions. A non-vanishing Weinberg angle would make sense in the deep interior of the Euclidian regions where the approximation as a small deformation of CP_2 makes sense.

4.4 Preferred extremal property for Einstein-Maxwell system

Consider now the preferred extremal property defined to be such that the action reduces to Chern-Simons action at space-like 3-surfaces at the ends of space-time surface and at light-like wormhole throats.

1. In Maxwell-Einstein system the field equations imply

$$j^\alpha = 0 \ . \tag{4.7}$$

so that the Maxwell action for extremals reduces automatically to a surface term assignable to the preferred 3-surfaces. Note that Higgs field could in principle serve as a source of Kähler field but its presence does not look like a good idea since it is not present in the field equations of TGD and because the resulting boundary term is not topological.

2. The condition

$$J = k \times *J \tag{4.8}$$

at preferred 3-surfaces guarantees that the surface term from Kähler action reduces to Abelian Chern-Simons term and one has hopes about almost topological QFT.

Since CP_2 type regions carry magnetic monopole charge and since the weak form of electric-magnetic duality implies that electric charge is proportional to the magnetic charge, one has electric charge without electric charge as Wheeler would express it. The identification of elementary building blocks as magnetic monopoles leads in TGD context to the picture about particle as Kähler magnetic flux tubes having opposite magnetic charges at their ends. It is not quite clear what the length of the tubes is. One possibility is Compton length and second possibility is weak length scale and the color confinement length scale. Note that in TGD the physical charges reside at the wormhole throats and correspond to massless fermions.

3. CP_2 is constant curvature space and satisfies Einstein equations with cosmological constant. The simplest manner to realize this is to add to the action constant volume term which is non-vanishing only in Euclidian regions. This term could be also interpreted as part of Maxwell action so that it is somewhat a matter of taste whether one speaks about cosmological constant or not. In any case, this would mean that the action contains a constant potential term

$$V = V_0 \times \frac{(1+sign(g))}{2} \quad , \tag{4.9}$$

where $sign(g) = -1$ holds true in Minkowskian regions and $sign(g) = 1$ holds true in Euclidian regions.

Note that for a piece of CP_2 V_0 term can be expressed is proportional to Maxwell action and by self-duality this is proportional to instanton action reducible to a Chern-Simons term so that V_0 is indeed harmless from the point of view of holography.

4. For Einstein-Maxwell system with similar constant potential in Euclidian regions curvature scalar vanishes automatically as a trace of energy momentum tensor so that no interior or surface term results and the only surface term corresponds to a pure Chern-Simons term for Maxwell field. This is exactly the situation also in quantum TGD. The constraint term guaranteeing the weak form of electric-magnetic duality implies that the metric couples to the dynamics and the theory does not reduce to a purely topological QFT.

5. In TGD framework a non-trivial theory is obtained only if one assumes that Kähler function corresponds apart from sign to either the Kähler action in the Euclidian regions or its negative in Minkowskian regions. This is required also by number theoretic vision. This implies a beautiful duality between field descriptions and particle descriptions.

   This also guarantees that the Kähler function reducing to Chern-Simons term is negative definite: this is essential for the existence of the functional integral and unitarity of the theory. This is due to the fact that Kähler action density as a sum of magnetic and electric energy densities is positive definite in Euclidian regions. This duality would be very much analogous to that implied by the possibility to perform Wick rotation in QFTs. Therefore it seems natural to postulate similar duality also in the proposed variant of quantized General Relativity.

6. The Kähler function of the WCW would be given by Chern-Simons term with a constraint expressing the weak form of electric-magnetic duality both in TGD and General Relativity. One should be able regard also in GRT framework WCW as a union of symmetric spaces with Kähler structure possessing therefore a maximal group of isometries. This is an absolutely essential prerequisite for the existence of WCW Kähler geometry. The symmetric spaces in the union are labelled by zero modes which do not contribute to the line element and would represent classical degrees of freedom essential for quantum measurement theory. In TGD the induced CP_2 Kähler form would represents such degrees of freedom and the quantum fluctuating degrees of freedom would correspond to symplectic group of $\delta M^4_\pm \times CP_2$.

   The difference between TGD and GRT would be that light-like 3-surfaces for all possible space-times containing Euclidian and Minkowskian regions would be considered for GRT type theory. In TGD these space-times are representable as surfaces of $M^4 \times CP_2$. In TGD framework the imbeddability assumption is crucial for the mathematical existence of the theory since it eliminates space-times with non-physical characteristics. The problem posed by arbitrarily large values of cosmological constants is one of the basic problems solved by this assumption. Also mass density is sub-critical for cosmologies with infinite duration and critical cosmologies are unique apart from their duration and quantum critical cosmologies replace inflationary cosmologies.

7. For vanishing Maxwell fields one obtains empty space Einstein equations and a lot of solutions. In TGD framework small deformations of the vacuum extremals for which Einstein tensor defines the energy momentum tensor of topologically condensed matter are in central role. For vacuum extremals the Chern-Simons form of Kähler action vanishes identically and one could consider assigning the gravitational analog of Chern-Simons term with the preferred 3-surfaces: this kind of term is discussed by Witten in this classic work about Jones polynomial. This term is a non-abelian version of Chern-Simons term and one must replace curvature tensor with its contraction with sigma matrices so that 4-D spinor structure is necessarily involved. The objection is that this term contains second derivatives. In TGD spinor structure is induced from that of $M^4\times CP_2$ and this kind of term need not make sense as such since gamma matrices are expressed in terms of imbedding space gamma matrices: among other things this resolves the problems caused by the non-existence of spinor structure for generic 4-geometries. The coupling to the metric however results from the constraint term expressing weak form of electric-magnetic duality.

   The difference between TGD and GRT would be basically due to the factor of scattering amplitudes coming from the duality expressing electric-magnetic duality and due to the fact that induced metric in terms of H-coordinates and Maxwell potential is expressible in terms of CP_2 coordinates. The latter implies topological field quantization and many-sheeted space-time crucial for the interpretation of quantum TGD.

4.5 Could the action contain also Higgs part?

One could criticize Maxwell-Einstein action with cosmological constant non-vanishing only in Euclidian regions and ask whether a coupling to Higgs field could change the situation. This is not the case.

1. If the action contains also Higgs part, Einstein-Higgs part of the action must reduce to a surface term. The trace $G^{\alpha\beta}$ equals to the trace of the Higgs energy momentum tensor and one obtains

$$-kG = kR = -T \ ,$$

   and

$$T = -(\nabla\Phi)^2 + 4V(\Phi) = -L_H + 2V(\Phi) \ .$$

   This gives

$$L_H + kR = 2L_H - 2V(\Phi) \ .$$

2. The kinetic term of Higgs field can be written as

$$(\nabla\Phi)^2 = \nabla\cdot(\Phi\nabla\Phi) - \Phi\nabla^2\Phi \ .$$

   The first term reduces to a surface term and second term can be expressed as

$$\Phi\nabla^2\Phi = -\Phi\frac{\partial V}{\partial\phi} \ .$$

   Similar formula applies also if the number of Higgs components is higher than one.

   The condition that only the surface term remains gives

$$-2V + \Phi\frac{\partial V}{\partial\Phi} = 0$$

   giving

$$V(\Phi) = \frac{m^2}{2}\Phi^2 \ . \tag{4.10}$$

3. The presence of constant term in V does not matter in field equations for Φ so that one can have

$$V(\Phi) = V_0 + \frac{m^2}{2}\Phi^2 \ . \tag{4.11}$$

In order to have both CP_2 like Euclidian regions and Reissner-Nordström type exterior solutions one must allow the Higgs potential to depend on the signature of the metric so that for massless Higgs favored by conformal invariance one would have

$$V(\Phi) \ = \ V_0 \times \frac{(1+sign(g))}{2} \ , \tag{4.12}$$

where one has $sign(g) = -1$ for Minkowskian regions and $sign(g) = 1$ for Euclidian regions. V_0 would be a constant of nature coding for CP_2 radius about 10^4 Planck lengths.

Since the introduction of Higgs field does not allow to circumvent the introduction of a term having interpretation in terms of cosmological constant and since one loses topological QFT property, it seems that the idea about Higgs is not good.

4.6 Could ZEO and the notion of CD make sense in GRT framework?

The notion of CD is crucial in ZEO and one can ask whether the notion generalizes to GRT context. In the previous arguments related to EG the notion of ZEO plays a fundamental role since it allows to replace $S-$matrix with $M-$matrix defining "complex square root" of density matrix.

1. In TGD framework CDs are Cartesian products of Minkowskian causal diamonds of M^4 with CP_2. The existence of double light-cones in curved space-time would be required and its is not clear whether this makes sense generally. TGD suggest that the scales of these diamonds defined in terms of the proper time distance between the tips are integer multiples of CP_2 scale defined in terms of the fundamental constant V_0 (the more restrictive assumption allowing only 2^n multiples would explain p-adic length scale hypothesis but would not allow the generalization of Kac-Moody algebra spanned by M-matrices). The difference between boundaries of GRT CDs and wormhole throats would be that four-metric would not be degenerate at CDs.

2. The conformal symmetries of light-cone boundary and light-like wormhole throats generalize also now since they are due to the metric 2-dimensionality of light-like 3-surfaces. It is however far from clear whether one can have anything something analogous to conformal variants of symplectic algebra of $\delta M^4_\pm \times CP_2$ and isometry algebra of $M^4 \times CP_2$.

   Could one perhaps identify four-momenta as parameters associated with the representations of the conformal algebras involved? This hope might be unrealistic in TGD framework: the basic idea behind TGD indeed is that Poincare invariance lost in GRT is retained if space-times are surfaces in $H = M^4 \times CP_2$. The reason is that that super-Kac-Moody symmetries correspond to localized isometries of H whereas the super-conformal algebra associated with the symplectic group is assignable to the light-like boundaries $\delta M^4_\pm \times CP_2$ of CD of H rather than space-time surface.

3. One could of course argue that some physical conditions on GRT -most naturally just the highly non-trivial mathematical existence of WCW Kähler geometry and spinor structure- could force the representability of physically acceptable 4-geometries as surfaces $M^4 \times CP_2$. If so, then also CDs would the same CDs as in TGD and quantization of GRT would lead to TGD and all the huge symmetries would emerge from quantum GRT alone.

   The first objection is that the induced spinor structure in TGD is not consistent with that natural in GRT. Second objection is that in TGD framework Einstein-Maxwell equations are not true in general and Einstein's equations can be assumed only in long length scales for the vacuum extremals of Kähler action. The Einstein tensor would characterize the energy momentum tensor assignable to the topologically condensed matter around these vacuum extremals and neither geometrically nor topologically visible in the resolution defined by very long length scale. If Maxwell field corresponds to em field in Minkowskian regions, the vacuum extremal property would make sense in scales where matter is electromagnetic neutral and em radiation is absent.

5 What can one conclude?

The previous considerations suggest that a surprisingly large piece of TGD can be applied also in GRT framework and raise the possibility about quantization of Einstein-Maxwell system in terms of Kähler geometry of WCW consisting of 3-geometries instead of 3-surfaces. One can even consider a new manner to understand TGD as resulting from the quantization of GRT in terms of WCW Kähler geometry in the space of 3-metrics realizing holography and making classical theory an exact part of quantum theory. Since the space-times allowed by TGD define a subset of those allowed by GRT one can ask whether the quantization of GRT leads to TGD or at least sub-theory of TGD. The arguments represented above however suggest that this is not the case. The generalization of S-matrix to a complex of U-matrix, S-matrix and algebra of M-matrices forced by ZEO gives a natural justification for the modification of EG allowing gravitons and giving up the rather nebulous idea about emergent space-time. Whether ZEO crucial for EG makes sense in GRT picture is not clear. A promising signal is that the generalization of EG to all interactions in TGD framework leads to a concrete interpretation of gravitational entropy and temperature, to a more precise view about how the arrow of geometric time emerges, to a more concrete realization of the old idea that matter antimatter asymmetry could relate to different arrows of geometric time (not however for matter and antimatter but for space-time sheets mediating attractive and repulsive long range interactions), and to the idea that the small value of cosmological constant could correspond to the small fraction of non-Euclidian regions of space-time with cosmological constant characterized by CP_2 size scale.

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