The description of E and B modes of CMB in the TGD framework

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Abstract

There are two key differences between inflation theory and TGD. In TGD, the almost constant value of the CMB temperature is due to quantum coherence in arbitrarily long scales rather than exponential expansion which does not look plausible. There is however expansion in the transition from the primordial cosmic string dominated phase in which space-time surfaces have 2-D string world sheets as M^4 projection, to monopole flux tubes liberating energy and leading to a radiation dominated cosmology. An entire sequence of phase transitions leading to the thickening of the monopole flux tubes is predicted, and interpreted as transitions between copies of standard model physics labelled by different p-adic mass scales predicted by TGD. If there is an exponential expansion, it is associated with this sequence.

So called B modes are the key prediction of the inflation theory. They are generated already in the inflationary period in the exponential expansion amplifying quantum fluctuations to cosmic scales. The primordial B modes are caused by gravitational waves and leave an imprint of primordial quantum fluctuation in cosmic scales. Their observation would be a victory of inflationary cosmology but their observation is extremely difficult due to the fact that also gravitational lensing transforms E modes to B modes.

The massless extremals (MEs) as counterparts of classical radiation fields provide a TGD based model for E and B modes. The prediction of the holography = holomorphy principle is that these modes are interchangeable locally. The local polarization vector for MEs is a holomorphic vector for which curl and divergence vanish apart from singularities, where the holomorphy fails. E and B modes differ only globally: for the B modes the coordinate lines of the polarization vector are closed curves around singularities. For E they connect singularities. The detected intensity vanishes outside the singular points,where it has a delta function type singularity. A natural interpretation as a vertex for photon emission/absorption.

1 Introduction

The inspiration for writing this article came from a discussion with Marko Manninen about a possible computer game, which could help to learn about modern physics, the ways to test it, and its problems. Inflation theory was one example considered. I have written about the relationship of TGD and inflation theory earlier, see for instance [L12, L11]. The rather dramatic steps of progress that have occurred in the understanding of TGD during this year [L10, L16, L21, L18, L17, L22, L20] inspired the writing of this article.

1.1 Two ways to understand the almost constancy of CMB temperature

Inflation theory provides the standard way to understand the almost constant value of the CMB temperature. TGD suggests an alternative way to understand this [L11].

1.1.1 Inflation as an explanation

Inflation theory (see this) has been the fashionable scenario of cosmology. Inflation theory was developed to solve the problem posed by the almost constant temperature of the cosmological microwave background. The idea is that this is due to an exponential expansion during the primordial cosmology amplifying a particular microscopic fluctuation to a particular cosmology. Multiverse is the unavoidable prediction. Inflation theory also predicts that the decay of Higgs-like inflaton fields carrying vacuum energy gives rise to ordinary matter.

Inflation theory predicts that CMB should have, besides so called E mode with polarization vector field, which is analogous to a gradient of a scalar, also B modes for which the direction of polarization vector field behaves like a curl of a vector field [E1, E2]. The motivation for the symbols E and B can be understood: in electrostatics the electric field E gradient of scalar potential and magnetic field B quite generally is a curl of a vector potential. E mode dominates over B mode. The E mode would be generated by density fluctuations and density is indeed a scalar. B mode has a character of a tensor and would be generated by gravitational waves.

The cosmology before the formation of galaxies and stars is a mere narrative for the simple reason that we cannot see the past before their formation and before the time when the Universe became transparent. The only hope is that the fluctuations of CMB related to its temperature and polarization patterns could carry information about the earlier period imprinted in CMB. In inflationary cosmology, the gravitational waves of the primordial cosmology would be amplified from microscopic scales to cosmological scales and could imprint themselves to the CMB.

If so, the identification of B mode from the CMB could provide information about primordial cosmology and even prove inflationary cosmology. The challenge is to extract the primordial B mode contribution from the CMB. The challenge is not easy. Also the gravitational lensing transforms E mode into B mode and these contributions should be subtracted so that only the primordial contribution would remain. A few years ago there was a claim about this but it turned out to not hold water.

1.1.2 Long length scale quantum coherence as TGD based explanation

In TGD, the possibility of quantum coherence in arbitrarily long scales explains the almost constant value of the CMB temperature. No primordial exponential expansion is needed although one cannot of course exclude it. String dominated cosmology does not however favour exponential expansion but there would be expansion be associated with the transition to radiation dominated cosmology in which cosmic strings would form tangles in which they would thicken to monopole flux tubes and emit ordinary matter. An entire hierarchy of this kind of transitions is predicted as phase transition between copies of hadron physics labelled by preferred p-adic primes. If the exponential expansion is not present, there is no hope that primordial cosmology could make itself visible in CMB.

The role of the decay of the inflaton field is taken by the transformation of cosmic strings as space-time surfaces with 2-D M^4 projection dominating in the primordial cosmology to monopole flux tubes with a 4-D M^4 projection followed by similar transition increasing the thickness of monopole flux tubes. This would liberate the classical energy of the cosmic string/flux tubes and transform it to ordinary matter.

In inflation theory exponential expansion would make it possible to transfer information from the microscopic quantum fluctuations to CMB. What about TGD? The primordial phase could make it visible in two ways.

1. At the level of the geometry of the space-time surface, cosmic strings thickening later to monopole flux tubes are the key players. The thickening of the monopole flux tubes would be analogous to inflaton decay producing ordinary matter and would give rise to the formation of galaxies and stars. The primordial flux tube network would evolve to what is behind the observed filament network (see this).

   Galaxies would correspond to the local tangles of very cosmic strings thickened to monopole flux tubes [L2, L4, L11]. The collisions of cosmic strings could be important and could generate spiral galaxies. This explains galactic dark matter in terms of the classical energy of long cosmic strings and makes testable predictions distinguishing TGD from ΛCDM and MOND scenarios [L13]. Also stars would be formed to local flux tube tangles. This network plays a key role in the TGD inspired astrophysics and cosmology. [L8, L9, L23, L19].

2. In TGD, the fractality implies that the physics looks the same in all scales and one can deduce what physics looks like even in the primordial period by using the fractality. TGD indeed replaces standard model physics with a hierarchy of scaled up standard model physics during primordial states the mass scales of the standard model physics would approach to CP_2 mass scale. Exaggerating somewhat, the earlier worlds would be scaled versions of this everyday world.

   Fractality encourages to ask whether the notion of particle generalizes to arbitrary scales so that the existing TGD based view of particles could make sense for the analogs particles of arbitrarily large sizes. The basic mechanisms of TGD inspired quantum biology could also be generalized by fractality. A highly non-trivial new element is quantum coherence in arbitrarily long scales.

3. Also particle physics description in terms of fundamental fermions, which are the only primary quantum fields in TGD [L18, L17, L20], is needed and exists now thanks to a dramatic progress in the understanding of Dirac equations for the free spinor fields of the embedding space $H = M^4 \times CP_2$ and for the induced spinors at the space-time surface.

1.2 About the mathematical definition of E and B modes

The following summarizes the intuitive description of the B mode given in [E1].

1. Polarization tensor P is defined in terms of correlation function for the components of the electric polarization of incoming radiation at a distant spherical surface surrounding the source.

   An approximation as a flat plane makes sense locally and a and b refer to the cartesian orthogonal coordinates of the plane. P is a tensor in 2-D sense since t in rotations of the plane by angle α it transforms by a phase factor $exp(i\alpha)$. One can also say that it has a conformal weight/spin 2.

2. The definition of the polarization tensor P is in terms of Stokes parameters Q and U as

$$P_{ab} = \frac{1}{\sqrt{2}} \left(\begin{array}{cc} Q(\theta,\phi) & U(\theta,\phi) \\ U(\theta,\phi) & -Q(\theta,\phi) \end{array} \right)$$

$$\begin{array}{l} Q = \langle E_x^2 - E_y^2 \angle \ , \\ U = i2\langle E_x E_y \langle \ . \end{array} \quad (1.1)$$

The averages $Q = \langle E_x^2 - E_y^2 \angle$ $U = i2\langle E_x E_y\langle$ at given point can be interpreted as averages of the real and imaginary parts E^2, where $E = E_x + iE_y$ of planar projection of electric field regarded as a complex number. This generalizes to curved surfaces such as a sphere. The average of Q corresponds to E mode and that of U to B mode.

It should be noticed that Q and U and transformed to each other in $\pi/2$ rotation.

3. The article [E1] about B mode explains how one can deduce information about $\phi = \phi_e + i\phi_b$ defined as a second antiholomorphic derivative $\phi = \partial_{\overline{w}}^2 P$ of the polarization tensor $P = Q+iU$ with respect to the conjugate $\overline{w}$ of the complex coordinate w of the surface. If ϕ is non-vanishing, one can derive parameters E and B, which at least intuitively, correspond to electric and magnetic polarizations or the incoming CMB radiation orthogonal to each other.

If the second antiholomorphic derivative is non-vanishing, the moduli squared of ϕ_e and ϕ_b giving information about the CMB intensities in E and B modes so that the ratio of these intensities can be measured.

The rigorous mathematical description is obtained by the polarization tensor of the CMB spectrum in terms of spin harmonics [E2] (in TGD CP_2 spinor harmonics for the embedding space spinor fields represent an example of this).

1. Depending on whether the physical quantity is scalar, vector, 2-tensor, etc..., one can assign with it spin 0,1,2,... and perform partial wave analysis by developing it as a sum of spin harmonics. This expansion determines the behavior of the field-like physical quantity.

2. Each harmonic has a well defined total angular momentum j as the sum of orbital angular momentum l and spin s is allowed by additivity of angular momentum. In the case of CBM, one considers 2-D spin harmonics at a very large sphere, which can be approximated with the plane locally so that the spin becomes conformal spin corresponding to the spin axis orthogonal to the plane.

There is however a problem. The relation between P and $\phi = \partial_{\overline{w}}^2 P$ must be invertible.

1. In the TGD framework, generalized holomorphy suggests that P is holomorphic so that one would have $\phi = \phi_e + i\phi_b = \partial_{\overline{w}}^2 P = 0$ at the 2-surface. Therefore the generalized conformal invariance for the polarization field $P = Q+iU$ would imply $\phi_e = 0$ and $\phi_b = 0$ and integrals for their moduli squared over the 2-surface vanish.

2. The situation changes if P has singularities at which the holomorphy is violated and $\partial_{\overline{w}}^2 P$ has a delta function singularity so that ϕ_e and ϕ_b are non-vanishing as delta function singularities. In the TGD framework, these singular points would correspond to vertices for particle emission, in particular photon emission. These photons would be detected. They could be also identified as interactions of monopole flux tubes arriving from the source.

The so called "massless extremals" [K1] provide the natural TGD description of E and B a modes and it indeed turns

1.3 What are the TGD counterparts of E and B modes?

In the sequel an attempt to understand what E and B modes are in TGD Universe and how the CMB is generated. There are two levels to be considered.

1. In the geometric description in terms of space-time surfaces as almost deterministic 4-D Bohr orbits for particles as 3-surfaces, and determined by the holography = holomorphy principle [L10, L16], the local QFT description in terms of gravitational and gauge fields is replaced with the holistic dynamics of the space-time surfaces determined by holography = holomorphy principle.

2. The local description as the TGD counterpart of the standard QFT description using induced gauge fields and induced metric appears in the fermionic sector. The identification of vertices for the creation of fermion pairs as 3-D edge singularities of the space-time surface violating holomorphy and identifiable as defects of the standard smooth structure [A2, A3, A1] transforming it to exotic smooth structure make possible fermion pair creation despite the fact that the spinor fields in H are free [L14, L6, L15]. Interactions without interactions, might Wheeler say.

The massless extremals (MEs) as TGD counterparts of classical radiation fields [K1, K2] provide a TGD based model for E and B modes. Holography = holomorphy principle predicts that these modes are locally interchangeable. The local polarization vector for MEs is a holomorphic vector for which curl and divergence vanish apart from singularities, where the holomorphy fails. E and B modes differ only globally: for the B modes the coordinate lines of the polarization vector are closed curves around singularities. For E they connect singularities. The detected intensity vanishes outside the singular points,where it has a delta function type singularity. A natural interpretation as a vertex for photon emission/absorption.

2 The TGD based view of E and B modes

The TGD based description of E and B modes differs from the standard description in that the dynamics of fields is replaced with the holographic classical dynamics of space-time of the space-time surface and the free fermion fields of the embedding space are the only fundamental quantum fields.

2.1 The basic vision behind the TGD view

A brief summary of key ideas possibly relevant for the understanding of E and B modes in the general context is in order.

2.1.1 Key ideas of TGD

Consider first the big picture.

1. In TGD framework the desciption of classical dynamics is as dynamics of 3-surfaces based on holography= holomorphy principle. This simplifies the description enormously. For instance, the E and B modes must correspond to dynamical patterns for the monopole flux tubes. Induced gauge potentials and metric enter only at the level of fermionic descriptions. The description in terms gravitational fields, gauge fields, and Higgs emerges only at the QFT limit.

2. In TGD, the elementary particles correspond to two-sheeted structures consisting of two Minkowskian parallel space-time sheets identifiable as monopole flux tubes and connected by Euclidian wormhole contacts [L20]. The fractality of the TGD Universe suggests that one can speak of elementary particles in this sense even in astrophysical and cosmological scales.

   The highly non-trivial implication suggested by large scale quantum coherence is that the emission of photons and other forms of radiation by these particles could mean emission of analogs of Bose-Einstein condensates. Indeed in TGD, inspired quantum biology communications would rely on the emission Bose-Einstein condensate-like structures of this kind, 3N-photons, and their receival by 3N-resonance. The signal would be coded by the modulations of the cyclotron frequency scale and would create a sequence of 3N-resonances.

3. Zero energy ontology (ZEO) implies that space-time surfaces as analogs of Bohr orbits replace particles as 3-surfaces as basic objects. The emission would take place for the entire Bohr orbit associated with the monopole flux tube. It could be a flux tube connecting observer to galactic nucleus or even to primordial Universe.

4. The vision that interactions are geometrically contact interactions, when generalized to 4-D Bohr orbits with the same Hamilton-Jacobi (Kähler) structure [L7], implies that interactions are associated with the intersections of space-time surfaces involved. The intersection consists of string world sheets.

   Also self-interactions are possible. One could define the notion of self-intersection purely mathematically by considering the intersection of the space-time surface with its small deformation. Self intersections can be also completely real! Two portions of space-time surface need not "know" that they belong to the same space-time surface! Instead of a discrete point like intersection consist 2-D string world sheets due to the same HJ structure!

5. The basic difference between inflation and TGD is that the exponential expansion is not present but quantum coherence is possible even in astrophysical and cosmological scales and explains the constancy of CMB temperature. This modifies the ideas about the production mechanism of radiation, in particular of CMB photons. It is probably not possible to obtain information about the very early Universe from the CMB but the fractality allows to gain this information theoretically.

2.1.2 About the interpretation for the failure of the conformal invariance

The failure of the generalized conformal invariance is crucial in TGD and the writing of this article forced to develop a more detailed view about it.

1. Holography = holomorphy vision [L10] implies that space-time surfaces are minimal surfaces for any general coordinate invariant classical action constructible in terms of the induced geometry. Minimal surface property implies that the second fundamental form having an interpretation as 8-D local acceleration for particles as 4-surfaces vanishes almost everywhere. Minimal surface equations are a non-linear counterpart of a massless field equation and the induced Dirac equation is the counterpart of the massless Dirac equation. Generalized holomorphy solves these equations trivially [L16].

2. The situation changes at the 3-D singularities, where the generalized conformal invariance fails. At these 3-D surfaces standard smooth structure [A2, A3, A1] has a defect but one has exotic smooth structure possible only in the 4-D case. The interpretation of the defect is as a vertex for fermion pair creation in induced classical fields [L14, L6, L15]. Fermion turns backwards in time and the edge corresponds to the defect of the smooth structure. Situation is analogous to that for Brownian motion for which acceleration is associated with the edges. Since also bosons are constructed from bound states of fermions and antifermions, this allows to describe also the creation of bosons.

3. The trace of the second fundamental form can be also interpreted as an analog of the Higgs field having also M^4 part. The generalized Higgs field vanishes by the minimal surface propertu and is non-vanishing only at the singularities. This is enough in order to obtain non-trivial interaction vertices.

4. Physically the non-vanishing generalizrf Higgs at the singularity corresponds to effective massivation of fermions and implies that M^4 chiralities are not conserved separately in the fermion current. The divergences of the fermion currents associated with different M^4 chiralities would vanish separately only for the exotic smooth structure. For the standard smooth

structure these divergences do not vanish separately but sum up to zero so that fermion number is conserved. The reason is that the turning of the light-like fermion line as a coordinate line of hypercomplex coordinate at the vertex looks like fermion pair creation breaking the chirality conservation or a change of fermion chirality.

Chirality non-conservation conforms with effective massivation due to the local failure of the Higgs to vanish: this is a non-linear counterpart of a massless field equation.

5. How to interpret the vanishing of the divergence of the fermion current? If it interprets it as the total amplitude for a pair creation, the outcome is zero. Nothing would happen in the vertex! This does not make sense. There is an analogous problem in general relativity: Einstein equations state the vanishing of all Noether currents related to general coordinate transformations. In this case one assigns an interpretation as physical quantity only to the energy momentum tensor.

   Could the second fundamental form as a generalized acceleration have the same role as acceleration has in Newton's equations. The force is what is measured. Could the remaining terms in the divergence serve as the counterpart of the force. These transitions are measured.

   If this is the correct interpretation, the sum of the vertices for the emission of a fermion pair by various terms in the induced Dirac action is proportional to the trace of the second fundamental form which vanishes in the interior of the space-time surfaces and is non-vanishing only at the singularities at which conformal symmetry is violated locally. The trace of the second fundamental form as a generalization of Higgs could be indeed a kind of God particle!

2.1.3 TGD inspired quantum biology as a guideline

TGD inspired quantum biology serves as a second guide line.

1. I have proposed the notion of dark DNA in which codons at the monopole flux tubes correspond dark proton triplets. Dark DNA double helices would occampany ordinary DNA double helices [L3, L1]. Dark variants make sense also for single RNA strands having a helical structure. TGD also suggests a universal realization of the genetic code in terms of hyperbolic 3-geometry and realized in terms of dark protons sequences [L5, ?].

   In the case of dark DNA as dark 3N-proton dark 3N-photons are emitted and received by a similar DNA strand by 3N-resonance. Cyclotron energies for dark proton triplets provide a frequency triplet representation of the genetic code. One can argue that in the generation of radiation by monopole flux tubes dark N-photons with large angular momentum is emitted.

2. Consider as an example a helical double strand of cosmic strings/monopole flux tubes associated with DNA strands. Suppose that the twisted DNA strand opens and therefore gets angular momentum. Does it emit a compensating this angular momentum as a spin of a twisted 3N-photon: could there ge an angular momentum transfer between the magnetic body of dark DNA and DNA. Could this generalize and happen universally for the monopole flux tube pairs? Could the helical rotation and twisting serve as analogs of B modes for the source.

   The communication between dark DNA strands realized in terms of monopole flux tubes realizing genetic codons as dark proton triplets. Communications could be in terms of dark 3N-photons analogous to Bose-Einstein (BE) condensates assignable to "massless extremals" (MEs) parallel to the flux tubes. 3N-resonance would be the basic communication mechanism as a generalization of the ordinary resonance.

3. The analog of dark DNA could generalize by the fractality predicting the generalization of standard model physics to a fractal hierarchy of standard model physics characterized by p-adic mass scales. The very early Universe could involve monopole flux tubes with particles having CP_2 mass scale.

4. By the fractality of the TGD Universe, the emission mechanism for N-photons could be universal and possible in all scales, in particular in the primordial cosmology. Monopole flux tubes contain sequence of N dark particles, say N dark protons, would the emitter and the

dark N-photon as analog of BE condensate could take the role of single photon. If we take fractality as a philosophy replacing length scale reductions completely seriously, we might be able to understand primordial cosmology and what follows it by using what we known biology and elementary particle physics as TGD describes them.

2.1.4 Some questions related to the notion of CMB

The proposed vision predicts a dramatic modification of cosmology for times before the formation of galaxies and galaxies [L11]. Primordial cosmology is cosmic string dominated. Later these transform to monopole flux tubes and liberate their classical energy as matter, very much the same way as in inflation and a transition to radiation dominated cosmology takes place. The description of E and B modes must be based on the dynamics of long scale dynamics of cosmic strings rather than the local dynamics of the induced metric.

There is a long list of questions to be considered.

1. The notions of hadron phase and quark-gluon plasma generalize in TGD [L20]. In what phase does the CMB reside: in the generalization of hadron phase or of quark-gluon phase? Photons can be regarded as color singlet bound states of quarks and of leptons, which both have an infinite number of color partial waves as fundamental fermions. Color confinement is involved also for photons as fermion-antifermion bound states. Photons can be massless or have a very small p-adic mass scale for all copies of the standard model in one-one correspondence with the multiplets of color partial waves for quarks and leptons. It is natural to assign photon to the generalization of the hadronic phase.

   The generalization of quark gluon phase at space-time surfaces, in the recent case the cosmic strings and monopole flux tubes, involves only fundamental fermions and classical indcuced gauge fields. Note that weak gauge fields identified as classical gluons with motivation coming the observation that the holonomy group $U(2)$ of CP_2 can be identified both as subgroup of the isometry group $SU(3)$ defining color group and as electroweak gauge group. Hence electroweak interactions would correspond to the spin aspect of color interaction and strong interactions to its orbital aspect [L20].

2. What is the role of Hagedorn temperature (see as an asymptotic temperature for the monopole flux tubes? Hagedorn temperature is due to the infinite number of degrees of freedom for string-like objects. Does it make the local heating of the CMB very difficult and explain why the temperature fluctuations are so small. Note that the Hagedorn temperature plays a key role in the TGD inspired quantum biology.

3. Could one assume that the polarization P at the fundametal as a tensor in plane or more general 2-surface is holomorphic apart from singularities identifiable vertices for a creation or annihilation of fermion pairs in classical induced gauge fields? In 2-D conformal field theories energy momentum tensor is holomorphic. In TGD this is not the case but polarization tensor could be holomorphic.

2.1.5 Detection of CMB in the TGD Universe

QFT limit is considered in the model behind the measurements but fundamental description must be based on the TGD view of space-time. How the standard description is modified in the TGD framework?

1. In the TGD framework, the description in terms of fields is replaced by a purely geometric description in terms of 4-D slightly non-determistic Bohr orbits. Therefore notions like E and B modes must be formulated in terms of the dynamics of the monopole flux tubes as Bohr orbits.

2. The photons would propagate along MEs parallel to radial monopole flux tubes emanating from the source, which is monopole flux tube in the distance past. The analog of the polarization tensor is associated with a region of large sphere surrounding the source intersecting the sphere at discrete set of points at which the conformal invariance fails and photon is generated.

3. In ZEO, the monopole flux tube plus ME from the source could be seen as a fundamental object analogous to source, one might speak of a dual source. Could it be used to describe the situation? The slight non-determinism of this flux tube dynamics would give rise to photon emission at the points of the flux tube. The monopole flux tube would generate a multiphoton state at ME or ME as its correlate in the detection. It would have the geometry assignable to the E or B mode.

   Are these views dual of each other? Is the statistical description at the sphere using polarization tensor equivalent with the statistical description associated with the monopole flux tube connecting the observer and source? What implications quantum coherence in scale of the flux tube has?

4. The cosmic string/flux tube network is extremely complex and develops by the splitting and reconnection and perhaps also by the replication of flux. Therefore one must ask whether the information about primordial cosmic string dominated cosmology can be deduced from CMB. On the other hand, the fractality of the TGD Universe means that this information can be deduced from much shorter length scales.

2.2 Summary of the geometric view of the E and B modes

In the TGD framework the situation is in many respects different from that in inflation theory.

2.2.1 The relationship of E and B modes to "massless extremals"

Massless extremals (MEs) [K1, K2] are extremely general solutions to practically any general coordinate invariant action expressible in terms of the induced geometry.

1. ME is analogous to a laser beam and describes dispersion free propagation with light velocity for precisely targeted waves along a cylinder-like structure which can be curved and even closed. ME is characterized by a local light-like wave vector k identifiable as a tangent vector of a light-like curve parametrized by a coordinate u and by a local polarization ϵ orthogonal to it. The CP_2 projection of ME is 2-dimensional.

2. MEs must satisfy holography = holomorphy principle and therefore must correspond to a Hamilton-Jacobi structure for which which the local wave vector k corresponds to a light-like tangent of the coordinate line of a hypercomplex coordinate $u = \int_0^u kdu$, where the integral is along a light-like curve for which the complex coordinate w of the H-J structure is constant. Note that the hypercomplex holomorphy implies that v is a passive coordinate which does not appear in the dynamics.

3. The local polarization vector ϵ can be interpreted as a complex vector at the 2-surface X^2 for which u and its hypercomplex conjugate v are constant and parametrized by a complex coordinate w. The generalization of the interpretation of the $k(u)$ is that ϵ is a complex tangent vector of a complex coordinate line $w = \int_0^w \epsilon(w)dw$, where the integral is any curve at X^2 such that u and v are constant.

What are the counterparts of E and B modes at the level of MEs?

1. The coordinate w would correspond to the complex coordinate of the sphere for CMB and k to the local direction of the arriving light ray which can be curved as in lensing. The intuitive expectation is that the for E and E modes ϵ corresponds to a gradient and for B modes to curl.

2. However, the holomorphy coded by Cauchy-Riemann equations implies that $\epsilon = dw/dz$ has vanishing divergence and curl and locally be interpreted either as a gradient or a curl. Situation changes only at the singularities in which the holomorphy fails.

   The difference between E and B modes is visible only at the level of field lines for ϵ. For B modes they are closed as for magnetic fields and for E modes they emerge from pole-like singularities and end up to a second singularity. This view conforms with the proposal that the polarization tensor is holomorphic apart from singularities and also with the finding that local E and B modes are interchangeable.

2.2.2 How to identify the geometric perturbations generating B modes?

In inflation theory, quantum fluctuation generates the B mode and exponential expansion amplifies it. In TGD, the counterpart of quantum fluctuations would be due to the weak failure of classical determinism assignable to flux tubes as Bohr orbits giving rise to a discrete and finite analog of path integral. The analogy with the opening of a DNA double strand suggests a more concrete mechanism. A portion of the double strand opens temporarily and emits dark N-photon propagating along the flux tube.

How to identify the geometric perturbations generating B modes?

1. In TGD, these perturbations are not at the fundamental level local perturbations of the metric but to perturbations of cosmic strings, or more generally of monopole flux tubes, as geometric objects. Also the pairs of helical cosmic strings and flux and their pairs are possible as well as pairs of flux tubes at parallel space-time sheets with Minkowskian signature of the induced metric connected by wormhole contacts with an Euclidean induced metric.

2. At the level of the flux tube dynamics, the perturbations giving rise to E and B type modes would be purely geometric.

   E modes, generated by density perturbations (scalars) in the standard cosmology, are possible for the monopole flux tubes. In TGD they would correspond to dark N-photons with a linear polarization expressible as a gradient and emitted in perturbations of non-twisted closed flux tubes. The counterpart of the density perturbation could be oscillatory variation of the flux tube thickness changing the linear density of the flux tube (string tension).

   The polarization tensor for the B modes suggests a perturbation of a rotating closed helical flux tube or a rotating pair of them. By conservation laws, the emitted N-photon would inherit the properties of this perturbation. Therefore B modes should be assignable to perturbations having a geometric interpretation in terms of twisting. A homological classification of B type perturbations using two integer valued winding numbers for a curve along the flux tubes.

3. Both modes could be analogous to the quantum fluctuations of the inflation model and the small failure of non-determinism for the Bohr orbits could give rise to this quantum fluctuation by replacing the quantum superposition of Bohr orbits with a new one. These modes as such would be stationary and generation of radiation would occur in the transition between these modes. It should be noticed that the classical non-determinism gives rise to a discrete analog of path integral.

2.2.3 Some quantitative estimates

1. What is the wavelength for these modes at this moment? Cosmic redshift associated with the inflation period is very large. In TGD exponential expansion of the flux tube does not look plausible and is not needed. In the cosmic expansion the thickness d of the flux tube increases as the p-adic prime characterizing it and also the p-adic length scale assignable to, say, nucleons of the scaled variant of hadron physics increases.

2. I have proposed a possible estimate for d as the geometric mean of the p-adic length scale assigned to the recent horizon size and Planck length. The rough estimate would be about $\sim 10^{-4}$ meters, roughly the size scale of a large neutron. Water blob with this size would have mass of order Planck mass. CMB wavelength is about 2 mm gives an alternative estimate. Flux tube thickness would correspond to the wavelength of CMB photons. CMB photon inside the flux tube. Interestingly, the gravitational Compton length of the Earth is equal to 1/2 of its Schwartschild radius and equals to 5 mm.

3. CMB temperature could relate to the thickness of the flux tube geometrically. The identification of the CMB temperature as a Hagedorn temperature for the flux tube would imply the stability of CMB temperature against heating and explain the smallness of the temperature fluctuations and therefore also of density fluctuations.

2.3 About the description at the level of fermions

The local description of the emission of CMB is basically in terms of a creation of fermion pairs in classical fields defined by induced spinor connection and metric.

1. The solutions of the modified/induced Dirac equation at the space-time surface [L18, L17, L20] provide the quantum field theoretic/string description of the scattering amplitudes and correspond to a generalization of the quark gluon phase of QCD. The initial and final states defined in terms of solutions of the Dirac equation in H in turn generalize the notion of the hadronic phase.

   Interactions would be contact interactions at the intersections of space-time surfaces as analogues of Bohr orbits, also self intersections are possible. For a common H-J structure the intersection would consist of 2-D string world sheets.

2. Conformal invariance (minimum surface property is universal) excludes vertices other than those at the singularities at which conformal invariance fails. Local violation of conformal invariance causes the generation of vertices for the emission of fermion pairs in induced classical fields. The vertices correspond to defects of the standard smooth structure. This makes also photon emission possible but these appear only in the final state as a generalization of hadron phase of QCD, not in the counterpart of the quark-gluon phase containing only free fermions [L20].

3. At the level of fermion emission giving rise to radiation as bound states of fermions and antifermions, induced metric and various induced gauge fields appear in the vertex. An interesting hypothesis is that the total divergence of the fermion current vanishes and that the sum of these vertices for the emission of a fermion pair possible assignable to some elementary particle is proportional the trace of the second fundamental form, which vanishes in the interiors of the space-time surfaces and is non-vanishing only at the singularities at which conformal symmetry is violated locally. These 3-D surfaces would correspond to edges of the space-time surface identifiable as defects of standard smooth structure and give rise to exotic smooth structure.

REFERENCES

Mathematics

[A1] Etesi G. Exotica or the failure of the strong cosmic censorship in four dimensions, 2015. Available at: http://arxiv.org/abs/1503.04945v4.

[A2] Gompf RE. Three exotic R^4's and other anomalies. *J. Differential Geometry*, 18:317–328, 1983.Available at: http://projecteuclid.org/download/pdf_1/euclid.jdg/1214437666.

[A3] Asselman-Maluga T and Brans CH. World Scientific. https://docs.google.com/document/d/1Hp656gzbKzlrHtmWvTUtOA5zsYZ4l5R3HHIe2eI-tPO/edit., 2007.

Cosmology and Astro-Physics

[E1] Kvok JY et al. What is the B mode in CMB polarization?, 2019. Available at: https://arxiv.org/pdf/1911.12488.

[E2] Kamionkowski M and Kovetz ED. The Quest for B Modes from Inflationary Gravitational Waves, 2015. Available at: https://arxiv.org/pdf/1510.06042. .

Books related to TGD

[K1] Pitkänen M. About Preferred Extremals of Kähler Action. In *Physics in Many-Sheeted Space-Time: Part I. https://tgdtheory.fi/tgdhtml/Btgdclass1.html*. Available at: https://tgdtheory.fi/pdfpool/prext.pdf, 2023.

[K2] Pitkänen M. Quantum Antenna Hypothesis. In *Bio-Systems as Self-Organizing Quantum Systems. https://tgdtheory.fi/tgdhtml/BbioSO.html*. Available at: https://tgdtheory.fi/pdfpool/tubuc.pdf, 2023.

Articles about TGD

[L1] Pitkänen M. About the Correspondence of Dark Nuclear Genetic Code and Ordinary Genetic Code. Available at: https://tgdtheory.fi/public_html/articles/codedarkcode.pdf., 2018.

[L2] Pitkänen M. TGD view about quasars. Available at: https://tgdtheory.fi/public_html/articles/meco.pdf., 2018.

[L3] Pitkänen M. An overall view about models of genetic code and bio-harmony. Available at: https://tgdtheory.fi/public_html/articles/gcharm.pdf., 2019.

[L4] Pitkänen M. Cosmic string model for the formation of galaxies and stars. Available at: https://tgdtheory.fi/public_html/articles/galaxystars.pdf., 2019.

[L5] Pitkänen M. Is genetic code part of fundamental physics in TGD framework? Available at: https://tgdtheory.fi/public_html/articles/TIH.pdf., 2021.

[L6] Pitkänen M. Intersection form for 4-manifolds, knots and 2-knots, smooth exotics, and TGD. https://tgdtheory.fi/public_html/articles/finitefieldsTGD.pdf., 2022.

[L7] Pitkänen M. Holography and Hamilton-Jacobi Structure as 4-D generalization of 2-D complex structure. https://tgdtheory.fi/public_html/articles/HJ.pdf., 2023.

[L8] Pitkänen M. Magnetic Bubbles in TGD Universe: Part I. https://tgdtheory.fi/public_html/articles/magnbubble1.pdf., 2023.

[L9] Pitkänen M. Magnetic Bubbles in TGD Universe: Part II. https://tgdtheory.fi/public_html/articles/magnbubble2.pdf., 2023.

[L10] Pitkänen M. About Langlands correspondence in the TGD framework. https://tgdtheory.fi/public_html/articles/Frenkel.pdf., 2024.

[L11] Pitkänen M. About the Recent TGD Based View Concerning Cosmology and Astrophysics. https://tgdtheory.fi/public_html/articles/3pieces.pdf., 2024.

[L12] Pitkänen M. About the TGD counterpart of the inflationary cosmology. https://tgdtheory.fi/public_html/articles/inflatgd2024.pdf., 2024.

[L13] Pitkänen M. Could the TGD view of galactic dark matter make same predictions as MOND? https://tgdtheory.fi/public_html/articles/MONDTGD.pdf., 2024.

[L14] Pitkänen M. Holography=holomorphy vision in relation to quantum criticality, hierarchy of Planck constants, and M^8-H duality. https://tgdtheory.fi/public_html/articles/holoholonumber.pdf., 2024.

[L15] Pitkänen M. What gravitons are and could one detect them in TGD Universe? https://tgdtheory.fi/public_html/articles/whatgravitons.pdf., 2024.

[L16] Pitkänen M. A more detailed view about the TGD counterpart of Langlands correspondence. https://tgdtheory.fi/public_html/articles/Langlands2025.pdf., 2025.

[L17] Pitkänen M. About Dirac equation in $H = M^4 \times CP_2$ assuming Kähler structure for M^4 . https://tgdtheory.fi/public_html/articles/HJdireq.pdf., 2025.

[L18] Pitkänen M. About the structure of Dirac propagator in TGD. https://tgdtheory.fi/public_html/articles/dirprop.pdf., 2025.

[L19] Pitkänen M. ANITA anomaly, JWST observation challenging the interpretation of CMB, and star formation in the remnant of a star. https://tgdtheory.fi/public_html/articles/ANITACMB.pdf., 2025.

[L20] Pitkänen M. Comparing the S-matrix descriptions of fundamental interactions provided by standard model and TGD. https://tgdtheory.fi/public_html/articles/hadroQCDTGD.pdf., 2025.

[L21] Pitkänen M. Gödel,Lawvere and TGD. https://tgdtheory.fi/public_html/articles/Gtgd.pdf., 2025.

[L22] Pitkänen M. Holography= holomorphy vision and a more precise view of partonic orbits . https://tgdtheory.fi/public_html/articles/HHpartons.pdf., 2025.

[L23] Pitkänen M. What makes the mini Big Bangs energetically possible? https://tgdtheory.fi/public_html/articles/minibbenerg.pdf., 2025.