TGD and Cosmology

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Contents

Abstract

A proposal for what might be called TGD inspired cosmology is made. The basic ingredient of this cosmology is the TGD counter part of the cosmic string. It is found that many-sheeted space-time concept, the new view about the relationship between inertial and gravitational four-momenta, the basic properties of the cosmic strings, zero energy ontology, the hierarchy of dark matter with levels labeled by arbitrarily large values of Planck constant: the existence of the limiting temperature (as in string model, too), the assumption about the existence of the vapor phase dominated by cosmic strings, and quantum criticality imply a rather detailed picture of the cosmic evolution, which differs from that provided by the standard cosmology in several respects but has also strong resemblances with inflationary scenario.

TGD inspired cosmology in its recent form relies on an ontology differing dramatically from that of GRT based cosmologies. Zero energy ontology (ZEO) states that all physical states have vanishing net quantum numbers so that all matter is creatable from vacuum. The hierarchy of dark matter identified as macroscopic quantum phases labeled by arbitrarily large values of Planck constant is second aspect of the new ontology. The values of the gravitational Planck constant assignable to space-time sheets mediating gravitational interaction are gigantic. This implies that TGD inspired late cosmology might decompose into stationary phases corresponding to stationary quantum states in cosmological scales and critical cosmologies corresponding to quantum transitions changing the value of the gravitational Planck constant and inducing an accelerated cosmic expansion.

1. Zero energy ontology

The construction of quantum theory leads naturally to ZEO stating that everything is creatable from vacuum. Zero energy states decompose into positive and negative energy parts having identification as initial and final states of particle reaction in time scales of perception longer than the geometro-temporal separation T of positive and negative energy parts of the state. If the time scale of perception is smaller than T, the usual positive energy ontology applies.

In ZEO inertial four-momentum is a quantity depending on the temporal time scale T used and in time scales longer than T the contribution of zero energy states with parameter $T_1 < T$ to four-momentum vanishes. This scale dependence alone implies that it does not make sense to speak about conservation of inertial four-momentum in cosmological scales. Hence it would be in principle possible to identify inertial and gravitational four-momenta and achieve strong form of Equivalence Principle. It however seems that this is not the correct approach to follow.

2. Dark matter hierarchy and hierarchy of Planck constants

Dark matter revolution with levels of the hierarchy labeled by values of Planck constant forces a further generalization of the notion of imbedding space and thus of space-time. One can say, that imbedding space is a book like structure obtained by gluing together infinite number of copies of the imbedding space like pages of a book: two copies characterized by singular discrete bundle structure are glued together along 4-dimensional set of common points. These points have physical interpretation in terms of quantum criticality. Particle states belonging to different sectors (pages of the book) can interact via field bodies representing space-time sheets which have parts belonging to two pages of this book. Dark matter hierarchy follows naturally from the non-determinism of Kähler action.

3. Quantum criticality

TGD Universe is quantum counterpart of a statistical system at critical temperature. As a consequence, topological condensate is expected to possess hierarchical, fractal like structure containing topologically condensed 3-surfaces with all possible sizes. Both Kähler magnetized and Kähler electric 3-surfaces ought to be important and string like objects indeed provide a good example of Kähler magnetic structures important in TGD inspired cosmology. In particular space-time is expected to be many-sheeted even at cosmological scales and ordinary cosmology must be replaced with many-sheeted cosmology. The presence of vapor phase consisting of free cosmic strings containing topologically condensed fermions is second crucial aspect of TGD inspired cosmology.

Quantum criticality of TGD Universe, which corresponds to the vanishing of second variation of Kähler action for preferred extremals - at least of the variations related to dynamical symmetries- supports the view that many-sheeted cosmology is in some sense critical. Criticality in turn suggests fractality. Phase transitions, in particular the topological phase transitions giving rise to new space-time sheets, are (quantum) critical phenomena involving no scales. If

the curvature of the 3-space does not vanish, it defines scale: hence the flatness of the cosmic time=constant section of the cosmology implied by the criticality is consistent with the scale invariance of the critical phenomena. This motivates the assumption that the new space-time sheets created in topological phase transitions are in good approximation modelable as critical Robertson-Walker cosmologies for some period of time at least.

These phase transitions are between stationary quantum states having stationary cosmologies as space-time correlates: also these cosmologies are determined uniquely apart from single parameter.

4. Only sub-critical cosmologies are globally imbeddable

It should be made clear that TGD inspired cosmology involves a vulnerable asumption. It is assumed that single-sheeted space-time surface is enough to model the cosmology. This need not to be the case. GRT limit of TGD is obtained by lumping together the sheets of many-sheeted space-time to a piece of Minkowski space and endowing it with an effective metric, which is sum of Minkowski metric and deviations of the induced metrics of space-time sheets from Minkowski metric. Hence the proposed models make sense only if GRT limits allowing imbedding as a vacuum extremal of Kähler action have special physical role.

TGD allows global imbedding of subcritical cosmologies. A partial imbedding of one-parameter families of critical and overcritical cosmologies is possible. The infinite size of the horizon for the imbeddable critical cosmologies is in accordance with the presence of arbitrarily long range fluctuations at criticality and guarantees the average isotropy of the cosmology. Imbedding is possible for some critical duration of time. The parameter labeling these cosmologies is scale factor characterizing the duration of the critical period. These cosmologies have the same optical properties as inflationary cosmologies. Critical cosmology can be regarded as a "Silent Whisper amplified to Bang" rather than "Big Bang" and transformed to hyperbolic cosmology before its imbedding fails. Split strings decay to elementary particles in this transition and give rise to seeds of galaxies. In some later stage the hyperbolic cosmology can decompose to disjoint 3-surfaces. Thus each sub-cosmology is analogous to biological growth process leading eventually to death.

5. Fractal many-sheeted cosmology

The critical cosmologies can be used as a building blocks of a fractal cosmology containing cosmologies containing ... cosmologies. p-Adic length scale hypothesis allows a quantitative formulation of the fractality. Fractal cosmology predicts cosmos to have essentially same optic properties as inflationary scenario but avoids the prediction of unknown vacuum energy density. Fractal cosmology explains the paradoxical result that the observed density of the matter is much lower than the critical density associated with the largest space-time sheet of the fractal cosmology. Also the observation that some astrophysical objects seem to be older than the Universe, finds a nice explanation.

6. Cosmic strings as basic building blocks of TGD inspired cosmology

Cosmic strings are the basic building blocks of TGD inspired cosmology and all structures including large voids, galaxies, stars, and even planets can be seen as pearls in a cosmic fractal necklaces consisting of cosmic strings containing smaller cosmic strings linked around them containing... During cosmological evolution the cosmic strings are transformed to magnetic flux tubes with smaller Kähler string tension and these structures are also key players in TGD inspired quantum biology.

The observed large voids would contain galactic cosmic strings at their boundaries. These voids would participate cosmic expansion only in average sense. During stationary periods the quantum states would be modelable using stationary cosmologies and during phase transitions increasing gravitational Planck constant and thus size of the large void they critical cosmologies would be the appropriate description. The acceleration of cosmic expansion predicted by critical cosmologies can be naturally assigned with these periods. Classically the quantum phase transition would be induced when galactic strings are driven to the boundary of the large void. The mechanism forcing the phase transition could be repulsive Coulomb energy associated with dark matter at strings if cosmic strings generate net em charge as a consequence of CP breaking (antimatter could reside inside cosmic strings) or a repulsive gravitational acceleration. The large values of Planck constant are crucial for understanding of living matter so that gravitation would play fundamental role also in the evolution of life and intelligence.

Some sections are devoted to the TGD counterpart of inflationary cosmology. From the beginning it has been clear that quantum criticality implying flatness of 3-space and thus criticality is the TGD counterpart for inflationary cosmology. Only after the recent findings about evidence for the polarization of CMB I realized that critical cosmology contains a period of very fast accelerating expansion and that both inflation and accelerating expansion much later are special cases of criticality. This leads to a rather detailed view about how the temperature fluctuations could emerged in TGD framework. The predecessor of inflationary cosmology would be cosmic string gas in the light-cone of Minkowski space and critical period would mean the emergence of space-time as we know it.

1 Introduction

TGD inspired cosmology in its recent form relies on an ontology differing dramatically from that of GRT based cosmologies. Zero energy ontology (ZEO) states that all physical states have vanishing net quantum numbers so that all matter is creatable from vacuum. The hierarchy of dark matter identified as macroscopic quantum phases labeled by arbitrarily large values of Planck constant is second aspect of the new ontology. The values of the gravitational Planck constant assignable to space-time sheets mediating gravitational interaction are gigantic unless the second interacting particle is microscopic, in which case the identification $h_{gr} = GMm/v_0 = h_{eff} = n \times h$ makes sense. This implies that TGD inspired late cosmology might decompose into stationary phases corresponding to stationary quantum states in cosmological scales and critical cosmologies corresponding to quantum transitions changing the value of the gravitational Planck constant and inducing an accelerated cosmic expansion.

1.1 Zero Energy Ontology

In zero energy ontology one replaces positive energy states with zero energy states with positive and negative energy parts of the state at the boundaries of future and past direct light-cones forming a causal diamond. All conserved quantum numbers of the positive and negative energy states are of opposite sign so that these states can be created from vacuum. “Any physical state is creatable from vacuum” becomes thus a basic principle of quantum TGD and together with the notion of quantum jump resolves several philosophical problems (What was the initial state of universe?, What are the values of conserved quantities for Universe, Is theory building completely useless if only single solution of field equations is realized?).

At the level of elementary particle physics positive and negative energy parts of zero energy state are interpreted as initial and final states of a particle reaction so that quantum states become physical events. Equivalence Principle would hold true in the sense that the classical gravitational four-momentum of the vacuum extremal whose small deformations appear as the argument of configuration space spinor field is equal to the positive energy of the positive energy part of the zero energy quantum state.

Zero energy states decompose into positive and negative energy parts having identification as initial and final states of particle reaction in time scales of perception longer than the geometro-temporal separation T of positive and negative energy parts of the state. If the time scale of perception is smaller than T, the usual positive energy ontology applies.

In zero energy ontology inertial four-momentum is a quantity depending on the temporal time scale T used and in time scales longer than T the contribution of zero energy states with parameter $T_1 < T$ to four-momentum vanishes. This scale dependence alone implies that it does not make sense to speak about conservation of inertial four-momentum in cosmological scales. Hence it would be in principle possible to identify inertial and gravitational four-momenta and achieve strong form of Equivalence Principle. It however seems that this is not the correct approach to follow.

Negative energy virtual gravitons represented by topological quanta having negative time orientation and hence also negative energy. The absorption of negative energy gravitons by photons could explain the gradual red-shifting of the microwave background radiation. Negative energy virtual gravitons give also rise to a negative gravitational potential energy. Quite generally, negative energy virtual bosons build up the negative interaction potential energy. An important constraint to TGD inspired cosmology is the requirement that Hagedorn temperature $T_H \sim 1/R$, where R is CP_2 size, is the limiting temperature of radiation dominated phase.

1.2 GRT And TGD

The relationship between TGD and GRT was understood quite recently (2014). GRT space-time as effective space-time obtained by replacing many-sheeted space-time with Minkowski space with effective metric determined as a sum of Minkowski metric and sum over the deviations of the induced metrices of space-time sheets from Minkowski metric. Poincare invariance suggests strongly classical form of Equivalence Principle (EP) for the GRT limit in long length scales at least expressed in terms of Einstein's equations in given resolution scale with space-time sheets with size smaller than resolution scale represented as external currents.

One can consider also other kinds of limits such as the analog of GRT limit for Euclidian space-time regions assignable to elementary particles. In this case deformations of CP_2 metric define a natural starting point and CP_2 indeed defines a gravitational instanton with very large cosmological constant in Einstein-Maxwell theory. Also gauge potentials of standard model correspond classically to superpositions of induced gauge potentials over space-time sheets.

1.3 Vacuum Extremals As Models For Cosmologies

The vacuum extremals are absolutely essential for the TGD based view about long length scale limit about gravitation. Effective GRT space time would be imbeddable as a vacuum extremal to H. This is just assumption albeit coming first in mind - especially so when one has not yet understood how GRT space-time emerges from TGD!

Already the Kähler action defined by CP_2 Kähler form J allows enormous vacuum degeneracy: any four-surface having Lagrangian sub-manifold of CP_2 as its CP_2 projection is a vacuum extremal. The dimension of these sub-manifolds is at most two. Robertson-Walker cosmologies correspond to vacua with respect to inertial energy and in fact with respect to all quantum numbers. They are not vacua with respect to gravitational charges defined as Noether charges associated with the curvature scalar. Also more general imbeddings of Einstein's equations are typically vacuum extremals with respect to Noether charges assignable to Kähler action since otherwise one ends up with conflict between imbeddability and dynamics. This suggests that physical states have vanishing net quantum numbers quite generally. The construction of quantum theory [K12, K6] indeed leads naturally to zero energy ontology stating that everything is creatable from vacuum.

1.4 Dark Matter Hierarchy And Hierarchy Of Planck Constants

The idea about hierarchy of Planck constants relying on generalization of the imbedding space was inspired both by empirical input (Bohr quantization of planetary orbits) and by the mathematics of hyper-finite factors of type II_1 combined with the quantum classical correspondence.

Quantum classical correspondence suggests that Jones inclusions [A1] have space-time correlates [K22, K11]. There is a canonical hierarchy of Jones inclusions labeled by finite subgroups of SU(2) [?] This leads to a generalization of the imbedding space obtained by gluing an infinite number of copies of H regarded as singular bundles over $H/G_a \times G_b$, where $G_a \times G_b$ is a subgroup of $SU(2) \times SU(2) \subset SL(2,C) \times SU(3)$. Gluing occurs along a factor for which the group is same. The generalized imbedding space has clearly a book like structure with pages of books intersecting along 4-D sub-manifold $M^2 \times S^2$, S^2 a geodesic sphere of CP_2 characterizing the choice of quantization axes. Entire configuration space is union over "books" corresponding to various choices of this sub-manifold.

The groups in question define in a natural manner the direction of quantization axes for for various isometry charges and this hierarchy seems to be an essential element of quantum measurement theory. Ordinary Planck constant, as opposed to Planck constants $\hbar_a = n_a\hbar_0$ and $\hbar_b = n_b\hbar_0$ appearing in the commutation relations of symmetry algebras assignable to M^4 and CP_2, is naturally quantized as $\hbar = (n_a/n_b)\hbar_0$, where n_i is the order of maximal cyclic subgroup of G_i. The hierarchy of Planck constants is interpreted in terms of dark matter hierarchy [K11]. What is also important is that $(n_a/n_b)^2$ appear as a scaling factor of M^4 metric so that Kähler action via its dependence on induced metric codes for radiative corrections coming in powers of ordinary Planck constant: therefore quantum criticality and vanishing of radiative corrections to functional integral over WCW does not mean vanishing of radiative corrections.

G_a would correspond directly to the observed symmetries of visible matter induced by the underlying dark matter [K11]. For instance, in living matter molecules with 5- and 6-cycles could directly reflect the fact that free electron pairs associated with these cycles correspond to $n_a = 5$ and $n_a = 6$ dark matter possibly responsible for anomalous conductivity of DNA [K11, K4] and recently reported strange properties of graphene [D1]. Also the tetrahedral and icosahedral symmetries of water molecule clusters could have similar interpretation [K9]. [D2].

A further fascinating possibility is that the observed indications for Bohr orbit quantization of planetary orbits [E11] could have interpretation in terms of gigantic Planck constant for underlying dark matter [K18] so that macroscopic and -temporal quantum coherence would be possible in astrophysical length scales manifesting itself in many manners: say as preferred directions of quantization axis (perhaps related to the CMB anomaly) or as anomalously low dissipation rates.

Since the gravitational Planck constant is proportional to the product of the gravitational masses of interacting systems, it must be assigned to the field body of the two systems and characterizes the interaction between systems rather than systems themselves. This observation applies quite generally and each field body of the system (em, weak, color, gravitational) is characterized by its own Planck constant.

In the gravitational case the order of G_a is gigantic and at least GM_1m/v_0, $v_0 = 2^{-11}$ the favored value. The natural interpretation is as a discrete rotational symmetry of the gravitational field body of the system having both gravimagnetic and gravi-electric parts. The subgroups of G_a for which order is a divisor of the order of G_a define broken symmetries at the lower levels of dark matter hierarchy, in particular symmetries of visible matter.

The number theoretically simple ruler-and-compass integers having as factors only first powers of Fermat primes and power of 2 would define a physically preferred sub-hierarchy of quantum criticality for which subsequent levels would correspond to powers of 2: a connection with p-adic length scale hypothesis suggests itself. Ruler and compass hypothesis implies that besides p-adic length scales also their 3- and 5- multiples should be important.

A crucially important implication of dark matter hierarchy is macroscopic quantum coherence in astrophysical scales. This means that astrophysical systems tend to retain their M^4 size during cosmic expansion and change their size only during quantum jumps increasing the value of Planck constant. Cosmological quantum states can be modeled in terms of stationary Robertson-Walker cosmologies, which are extremals of curvature scalar. These cosmologies are determined apart from single parameter and string dominated having infinite horizon size.

Quantum phase transitions between stationary cosmologies are modellable in terms of quantum critical cosmologies which are also determined apart from single parameter. They correspond to accelerated cosmic expansion having interpretation in terms of increase of quantum scale due to the increases of gravitational Planck constant.

1.5 Quantum Criticality And Quantum Phase Transitions

TGD Universe is quantum counterpart of a statistical system at a critical temperature. As a consequence, topological condensate is expected to possess hierarchical, fractal like structure containing topologically condensed 3-surfaces with all possible sizes. Both Kähler magnetized and Kähler electric 3-surfaces ought to be important and string like objects indeed provide a good example of Kähler magnetic structures important in TGD inspired cosmology. In particular space-time is expected to be many-sheeted even at cosmological scales and ordinary cosmology must be replaced with many-sheeted cosmology. The possible presence of vapor phase consisting of free cosmic strings and possibly also elementary particles is second crucial aspects of TGD inspired cosmology.

Quantum criticality of TGD Universe supports the view that many-sheeted cosmology is in some sense critical, at least during quantum phase transitions. Criticality in turn suggests fractality. Phase transitions, in particular the topological phase transitions giving rise to new space-time sheets, are (quantum) critical phenomena involving no scales. If the curvature of the 3-space does not vanish, it defines scale: hence the flatness of the cosmic time=constant section of the cosmology implied by the criticality is consistent with the scale invariance of the critical phenomena. This motivates the assumption that the new space-time sheets created in topological phase transitions are in good approximation modellable as critical Robertson-Walker cosmologies for some period of time at least. It turns out that the critical cosmologies are naturally assignable to phase transitions and quantum criticality.

1.6 Critical And Over-Critical Cosmologies Are Highly Unique

Any one-dimensional sub-manifold of CP_2 allows global imbeddings of subcritical cosmologies whereas for a given 2-dimensional Lagrange manifold of CP_2 critical and overcritical cosmologies allow only one-parameter family of partial imbeddings.

The infinite size of the horizon for the imbeddable critical cosmologies is in accordance with the presence of arbitrarily long range fluctuations at criticality and guarantees the average isotropy of the cosmology. Imbedding is possible for some critical duration of time. The parameter labeling these cosmologies is a scale factor characterizing the duration of the critical period. These cosmologies have the same optical properties as inflationary cosmologies but exponential expansion is replaced with logarithmic one.

Cosmic expansion is accelerated for critical cosmologies. This gives good hopes of avoiding the introduction of cosmological constant and exotic forms of matter such as quintessence. Critical cosmologies might be completely universal and assignable to any quantum phase transitions in proper length scale. Dark matter hierarchy realized in terms of gigantic values of gravitational Planck constant predicts that even astrophysical systems are macroscopic quantum systems at the level of dark matter. This means that their M^4 size remains constant during cosmic expansion and can change only in quantum jump increasing the value of Planck constant. Critical cosmologies would be assigned to this kind of phase transitions occurring for large voids [K7].

Critical cosmology can be regarded as a "Silent Whisper amplified to Bang" rather than "Big Bang" and transformed to hyperbolic cosmology before its imbedding fails. Split strings decay to elementary particles in this transition and give rise to seeds of galaxies. In some later stage the hyperbolic cosmology can decompose to disjoint 3-surfaces. Thus each sub-cosmology is analogous to biological growth process leading eventually to biological death.

Critical and stationary cosmologies for which gravitational charges are conserved can be used as a building blocks of a fractal cosmology containing cosmologies containing... cosmologies. p-Adic length scale hypothesis allows a quantitative formulation of the fractality [K18]. Fractal cosmology predicts cosmos to have essentially same optical properties as inflationary scenario but avoids the prediction of unknown vacuum energy density. Fractal cosmology explains the paradoxical result that the observed density of the matter is much lower than the critical density associated with the largest space-time sheet of the fractal cosmology. Also the observation that some astrophysical objects seem to be older than the Universe, finds a nice explanation.

The key difference between inflationary and quantum critical cosmologies relates to the interpretation of the fluctuations of the microwave background. In the inflationary option fluctuations are amplified to long length scale fluctuations during inflationary expansion. In quantum critical cosmology the fluctuations be assigned to the quantum critical period accompanying macroscopic quantum fluctuations of the dark matter appearing in very long length scales during the phase transition so that no inflationary expansion is needed. Sub-critical cosmology is predicted after the inflationary period.

1.7 Cosmic Strings As Basic Building Blocks Of TGD Inspired Cosmology

Cosmic strings are the basic building blocks of TGD inspired cosmology and all structures including large voids, galaxies, stars, and even planets can be seen as pearls in a cosmic fractal necklaces consisting of cosmic strings containing smaller cosmic strings linked around them containing... During cosmological evolution the cosmic strings are transformed to magnetic flux tubes with smaller Kähler string tension and these structures are also key players in TGD inspired quantum biology.

Cosmic strings are of form $X^2 \times Y^2 \subset M^4 \times CP_2$, where X^2 corresponds to string orbit and Y^2 is a complex sub-manifold of CP_2. The gravitational mass of cosmic string is $M_{gr} = (1-g)/4G$, where g is the genus of Y^2. For $g = 1$ the mass vanishes. When Y^2 corresponds to homologically trivial geodesic sphere of CP_2 the presence of Kähler magnetic field is however expected to generate inertial mass which also gives rise to gravitational mass visible as asymptotic behavior of the metric of space-time sheet at which the cosmic string has suffered topological condensation. The corresponding string tension is in the same range that for GUT strings and explains the constant velocity spectrum of distant stars around galaxies.

For $g > 1$ the gravitational mass is negative. This inspires a model for large voids as space-time regions containing $g > 1$ cosmic string with negative gravitational energy and repelling the galactic $g = 0$ cosmic strings to the boundaries of the large void.

These voids would participate cosmic expansion only in average sense. During stationary periods the quantum states would be modellable using stationary cosmologies and during phase transitions increasing gravitational Planck constant and thus size of the large void they critical cosmologies would be the appropriate description. The acceleration of cosmic expansion predicted by critical cosmologies can be naturally assigned with these periods. Classically the quantum phase transition would be induced when galactic strings are driven to the boundary of the large void by the antigravity of big cosmic strings with negative gravitational energy. The large values of Planck constant are crucial for understanding of living matter so that gravitation would play fundamental role also in the evolution of life and intelligence.

1.8 Topics Of The Chapter

In the following this scenario is described in detail.

1. Basic ingredients of TGD inspired cosmology are introduced. The consequences of the imbeddability requirement are analyzed. The basic properties of cosmic strings are summarized and simple model for vapor phase as consisting of critical density of cosmic strings are introduced. Additional topics are thermodynamical aspects of cosmology, in particular the new view about second law and the consequences of Hagedorn temperature. Non-conservation of gravitational momentum is considered.

2. The evolution of the fractal cosmology is described in more detail.

3. TGD inspired cosmology is compared to inflationary scenario: in particular, the TGD based explanation for the recently observed flatness of 3-space and a possible solution to the Hubble constant controversy are discussed. Also the latest BICEP results providing claimed to demonstrate the presence of graviton interactions with CMB are discussed.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://tgdtheory.fi/cmaphtml.html` [L3]. Pdf representation of same files serving as a kind of glossary can be found at `http://tgdtheory.fi/tgdglossary.pdf` [L4]. The topics relevant to this chapter are given by the following list.

- TGD and GRT [L6]
- TGD inspired cosmology [L7]
- Cosmic strings [L5]
- 4-D spin glass degeneracy [L2]

2 Basic Ingredients Of TGD Inspired Cosmology

In this section the general principles and ingredients of the TGD inspired cosmology are discussed briefly.

2.1 Many-Sheeted Space-rime Defines A Hierarchy Of Smoothed Out Space-times

The notion of quantum average space-time (see **Fig.** `http://tgdtheory.fi/appfigures/manysheeted.jpg` or **Fig.** 9 in the appendix of this book) obtained by smoothing out details below the scale of resolution was inspired by renormalization group philosophy and for long time I regarded as the counterpart of GRT space-time. The rough idea was that quantum average effective space-times correspond to the preferred extremals of the Kähler action associated with the maxima of the

Kähler function. Therefore the dynamics of the quantum average effective space-time is fixed and the stationarity requirement for the effective action should only select some physically preferred maxima of the Kähler function. The topologically trivial space-time of classical GRT cannot directly correspond to the topologically highly nontrivial TGD space-time but should be obtained only as an idealized, length scale dependent and essentially macroscopic concept. This allows the possibility that also the dynamics of the effective smoothed out space-times is determined by the effective action.

The space-time in length scale L would be obtained by smoothing out all topological details (particles) and by describing their presence using various densities such as energy momentum tensor $T_{\#}^{\alpha\beta}$ and Yang Mills current densities $J_{a\#}^{\alpha}$ serving as sources of classical electro-weak and color gauge fields (see **Fig. 1**). It is important to notice that the smoothing out procedure eliminates elementary particle type boundary components in all length scales: this suggests that the size of a typical elementary particle boundary component sets lower limit for the scale, where the smoothing out procedure applies.

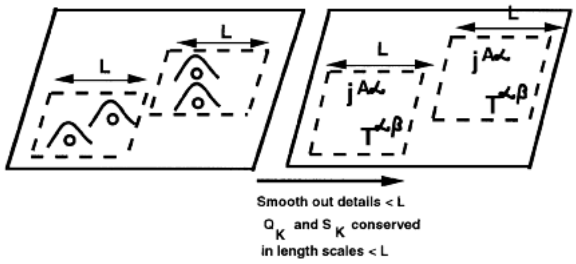

Figure 1: Intuitive definition of length scale dependent space-time

This notion can be critized.

1. The identification of smoothed out space-time as an extremal of Kähler action - most naturally vacuum extremal - is perhaps too strong. In particular, single sheetedness is too strong assumption if one assumes that the effective metric is induced metric. The identification also implicitly assumes single-sheetedness above the cutoff length scale.

2. The full realization that space-time of TGD Universe is many-sheeted in all scales led to the idea that GRT space-time is obtained by replacing the sheets of the many-sheeted space-time with Minkowski space endowed with effective metric which is sum of flat Minkowski metric and deviations of the metrics of the space-time sheets from Minkowski metric. This is the metric which defines the force experienced by test particle. It is of course possible that vacuum extremals are good approximations for the effective metric in asymptotic regions: typically in situations in which single sheet dominates.

3. The resulting picture would look like follows. Finite length scale resolution implies that the topological inhomogenities (space-time sheets and other topological inhomogenities) are treated as point-like objects and described in terms of energy momentum tensor of matter and various currents coupling to effective YM fields and effective metric important in length scales above the resolution scale. Einstein's equations with coupling to gauge fields and matter relate these currents to the Einstein tensor and metric tensor of the effective metric of M^4. Einstein's equations express Equivalence Principle and reduce it to Poincare invariance. For preferred extremals representable as graphs for map from $M^4 \rightarrow CP_2$ vanishing of the divergence of energy momentum tensor is highly suggestive and would in GRT framework lead to Einstein's equations: for preferred extremals this need not be the case but cannot excluded. The topological inhomogenities below cutoff scale serve determine the curvature of the effective metric. Gravitational constant and cosmological constant are predictions.

If one accepts (as I did for long time) the conjecture that effective metric can be expressed as induced metric for vacuum extremals one ends up with rather interesting vision. The smoothing out of details might not only activity of a theoretician, but that the many-sheeted space-time itself can be said to perform renormalization theory.

1. In TGD framework classical space-time is much more than a fiction produced by the stationary phase approximation. The localization in the so called zero modes, which corresponds to state function reduction in TGD, which occurs in each quantum jump (the delicacies due to macro-temporal quantum coherence will not be discussed here) means that the superposition of space-time surfaces in the final state of quantum jump, consists of space-time surfaces equivalent from the point of view of observer.

2. The notion of many-sheeted space-time predicts a hierarchy of space-time sheets labeled by p-adic primes $p \simeq 2^k$, k integer with primes and prime powers being in preferred role. The space-time sheets at a given level of hierarchy play a role of particles topologically condensed at larger space-time sheets. Hence the physics at larger space-time sheets is quite concretely a smoothed out version of the physics at smaller space-time sheets. Many-sheeted space-time itself performs renormalization group theory, and p-adic primes characterizing the sizes of the space-time sheets correspond to the fixed points of the renormalization group evolution.

3. There are good reasons to expect that the the Kähler action vanishes for large enough space-time sheets, and that space-time sheets result as small deformations of the vacuum extremals at the long length scale limit. The equations derived from Einstein-Hilbert action for the induced metric can be posed as an additional constraint on stationary vacuum extremals for which the gravitational four momentum current is conserved. It must be however emphasized that the structure of Einstein tensor as a source of the wave equation for the metric is enough to guarantee that gravitational masses make themselves visible in the asymptotic behavior of the metric.

   An important difference to the standard view is that energy momentum tensor is defined by the Einstein tensor (plus possible contribution of metric rather than vice versa. EYM equations cannot in general be satisfied by induced metric without the introduction of particle currents. This conforms with the view that Einstein's equations relate to a statistical description of matter in terms of both particle densities and classical fields. The imbeddability to $H = M^4_+ \times CP_2$ means a rich spectrum of predictions not made by GRT. TGD inspired cosmology and TGD based model for the final state of the star are good examples of these predictions, and are consistent with experimental facts. One must however emphasize that the imbeddability of the effective GRT space-time might be un-necessarily strong assumption.

   Of course, already the postulate that microscopic theory behind TGD is based on TGD space-time is extremely powerful since the space-time surfaces as preferred extremals are extremely simple. One can even hope that the existing preferred extremals define a considerable fraction of the most interesting extremals (note however that explicit solutions representing Kähler magnetic and electric flux quanta are not known). The complexity would emerge only when one lumps the space-time sheets together.

4. Quantum measurement theory with a finite measurement resolution formulated in terms of Jones inclusions replacing effectively complex numbers as coefficient field of Hilbert space with non-commutative von Neumann algebra is the most recent formulation for the finite measurement resolution and leads to the rather fascinating vision about quantum TGD [K22, K11]. This formulation should have also a counterpart at space-time level and combined with number theoretical vision it leads to the emergence of discretization at space-time level realized in terms of number theoretical braids.

Dark matter hierarchy whose levels are labeled by the values of Planck constant brings in also something genuinely new.

1. Dark matter hierarchy means multi-sheetedness of space-time surfaces but single-sheetedness of 3-surfaces at the ends of space-time surfaces located at the boundaries of causal diamonds. [K12, K11]. This multi-sheetedness is essentially due to the non-determinism of Kähler

action. Planck constant actually gives the number of sheets or more precisely, conformal equivalence classes of them, resulting from the failure of complete determinism. This kind of non-determinism is expected for the "field bodies" mediating various interactions and gravitational field bodies have a gigantic value of Planck constant.

2. The description of this hierarchy at the level of imbedding space means the replacement of the effectie imbedding space with a book like structure whose pages are copies of imbedding space endowed with a finite and singular bundle projection corresponding to the group $Z_{n_a} \times Z_{n_b} \subset SO(3) \times SU(3)$. These groups act as discrete symmetries of field bodies.

3. The choice of these discrete subgroups realizes the choice of angular momentum and color quantization axes at the level of imbedding space and thus realizes quantum classical correspondence. Any two pages of this book with 8-D pages intersect along common at most 4-D sub-manifold and the partonic 2-surfaces in the intersection can regarded as quantum critical systems in the sense that they correspond to a critical point of a quantum phase transition in general changing the value of Planck constant. Field bodies are four-surfaces mediating interactions between four-surfaces at different pages of this book.

4. The value of Planck constant makes itself visible in the scaling of M^4 part of the metric of H appearing in Kähler action. The scaling factor of M^4 metric m_{kl} equals to $(\hbar/\hbar_0)^2 = (n_a/n_b)^2$ as is clear from the fact that the Laplacian part of Schrödinger equation is at same time proportional to the contravariant metric and to $1/\hbar^2$. This means that radiative corrections are coded by the nonlinear dependence of the Kähler action on the induced metric. This means that all radiative corrections assignable to functional integral defined by exponent of Kähler function can vanish for preferred values of Kähler coupling strength. Number theoretic arguments require this.

Robertson-Walker cosmologies are the basic building block of standard cosmologies and sub-critical R-W cosmologies have a very natural place in TGD framework as Lorentz invariant cosmologies. Inflationary cosmologies are replaced with critical cosmologies being parameterized by a single parameter telling the duration of the critical cosmology. Over-critical cosmologies are also possible and have the same form as critical cosmologies and finite duration.

2.1.1 Why Robertson-Walker cosmologies?

Robertson Walker cosmology, which is a vacuum extremal of the Kähler action, is a reasonable idealization only in the length scales, where the density of the Kähler charge vanishes. Since (visible) matter and antimatter carry Kähler charges of opposite sign this means that Kähler charge density vanishes in length scales, where matter-antimatter asymmetry disappears on the average. This length scale is certainly very large in present day cosmology: in the proposed model for cosmology its present value is of the order of 10^8 light years: the size of the observed regions containing visible matter predominantly on their boundaries [E32]. That only matter is observed could be understood if it resides dominantly outside cosmic strings and antimatter inside cosmic strings.

Robertson Walker cosmology is expected to apply in the description of the condensate locally at each condensate level and it is assumed that the GRT based criteria for the formation of "structures" apply. In particular, the Jeans criterion stating that density fluctuations with size between Jeans length and horizon size can lead to the development of the "structures" will be applied.

2.1.2 Imbeddability requirement for RW cosmologies

Standard Robertson-Walker cosmology is characterized by the line element [E27]

$$ds^2 = f(a)da^2 - a^2(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2) \ , \tag{2.1}$$

where the values $k = 0, \pm 1$ of k are possible.

The line element of the light cone is given by the expression

$$ds^2 = da^2 - a^2(\frac{dr^2}{1+r^2} + r^2 d\Omega^2) \ . \tag{2.2}$$

Here the variables a and r are defined in terms of standard Minkowksi coordinates as

$$\begin{aligned} a &= \sqrt{(m^0)^2 - r_M^2} \ , \\ r_M &= ar \ . \end{aligned} \tag{2.3}$$

Light cone clearly corresponds to mass density zero cosmology with $k = -1$ and this makes the case $k = -1$ is rather special as far imbeddings are considered since any Lorentz invariant map $M^4_+ \to CP_2$ defines imbedding

$$s^k = f^k(a) \ . \tag{2.4}$$

Here f^k are arbitrary functions of a.

$k = -1$ requirement guarantees imbeddability if the matter density is positive as is easy to see. The matter density is given by the expression

$$\rho = \frac{3}{8\pi G a^2}(\frac{1}{g_{aa}} + k) \ . \tag{2.5}$$

A typical imbedding of $k = -1$ cosmology is given by

$$\begin{aligned} \phi &= f(a) \ , \\ g_{aa} &= 1 - \frac{R^2}{4}(\partial_a f)^2 \ . \end{aligned} \tag{2.6}$$

where ϕ can be chosen to be the angular coordinate associated with a geodesic sphere of CP_2 (any one-dimensional sub-manifold of CP_2 works equally well). The square root term is always positive by the positivity of the mass density and the imbedding is indeed well defined. Since g_{aa} is smaller than one, the matter density is necessarily positive.

2.1.3 Critical and over-critical cosmologies

TGD allows the imbeddings of a one-parameter family of critical over-critical cosmologies. Critical cosmologies are however not inflationary in the sense that they would involve the presence of scalar fields. Exponential expansion is replaced with a logarithmic one so that the cosmologies are in this sense exact opposites of each other. Critical cosmology has been used hitherto as a possible model for the very early cosmology. What is remarkable that this cosmology becomes vacuum at the moment of “Big Bang” since mass density behaves as $1/a^2$ as function of the light cone proper time. Instead of “Big Bang” one could talk about “Small Whisper amplified to bang” gradually. This is consistent with the idea that space-time sheet begins as a vacuum space-time sheet for some moment of cosmic time.

As an imbedded 4-surface this cosmology would correspond to a deformed future light cone having its tip inside the future light cone. The interpretation of the tip as a seed of a phase transition is possible. The imbedding makes sense up to some moment of cosmic time after which the cosmology becomes necessarily hyperbolic. At later time hyperbolic cosmology stops expanding and decomposes to disjoint 3-surfaces behaving as particle like objects co-moving at larger cosmological space-time sheet. These 3-surfaces topologically condense on larger space-time sheets representing new critical cosmologies.

Consider now in more detail the imbeddings of the critical and overcritical cosmologies. For $k = 0, 1$ the imbeddability requirement fixes the cosmology almost uniquely. To see this, consider as an example of $k = 0/1$ imbedding the map from the light cone to S^2, where S^2 is a geodesic sphere of CP_2 with a vanishing Kähler form (any Lagrage manifold of CP_2 would do instead of S^2). In the standard coordinates (Θ, Φ) for S^2 and Robertson-Walker coordinates (a, r, θ, ϕ) for future light cone (, which can be regarded as empty hyperbolic cosmology), the imbedding is given as

$$\begin{aligned} sin(\Theta) &= \frac{a}{a_1} \ , \\ (\partial_r \Phi)^2 &= \frac{1}{K_0}\left[\frac{1}{1-kr^2} - \frac{1}{1+r^2}\right] \ , \\ K_0 &= \frac{R^2}{4a_1^2} \ , \ k = 0,1 \ , \end{aligned} \tag{2.7}$$

when Robertson-Walker coordinates are used for both the future light cone and space-time surface.

The differential equation for Φ can be written as

$$\partial_r \Phi = \pm \sqrt{\frac{1}{K_0}\left[\frac{1}{1-kr^2} - \frac{1}{1+r^2}\right]} \ . \tag{2.8}$$

For $k = 0$ case the solution exists for all values of r. For $k = 1$ the solution extends only to $r = 1$, which corresponds to a 4-surface $r_M = m^0/\sqrt{2}$ identifiable as a ball expanding with the velocity $v = c/\sqrt{2}$. For $r \rightarrow 1$ Φ approaches constant Φ_0 as $\Phi - \Phi_0 \propto \sqrt{1-r}$. The space-time sheets corresponding to the two signs in the previous equation can be glued together at $r = 1$ to obtain sphere S^3.

The expression of the induced metric follows from the line element of future light cone

$$ds^2 = da^2 - a^2(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2) \ . \tag{2.9}$$

The imbeddability requirement fixes almost uniquely the dependence of the S^2 coordinates a and r and the g_{aa} component of the metric is given by the same expression for both $k = 0$ and $k = 1$.

$$\begin{aligned} g_{aa} &= 1 - K \ , \\ K &\equiv K_0 \frac{1}{(1-u^2)} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{2.10}$$

The imbedding fails for $a \geq a_1$. For $a_1 \gg R$ the cosmology is essentially flat up to immediate vicinity of $a = a_1$. Energy density and "pressure" follow from the general equation of Einstein tensor and are given by the expressions

$$\begin{aligned} \rho &= \frac{3}{8\pi G a^2}(\frac{1}{g_{aa}} + k) \ , \ k = 0, \pm 1 \ , \\ \frac{1}{g_{aa}} &= \frac{1}{1-K} \ , \\ p &= -(\rho + \frac{a\partial_a \rho}{3}) = -\frac{\rho}{3} + \frac{2}{3}K_0 u^2 \frac{1}{(1-K)(1-u^2)^2}\rho_{cr} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{2.11}$$

Here the subscript "cr" refers to $k = 0$ case. Since the time component g_{aa} of the metric approaches constant for very small values of the cosmic time, there are no horizons associated with this metric. This is clear from the formula

$$r(a) = \int_0^a \sqrt{g_{aa}}\frac{da}{a}$$

for the horizon radius.

g_{aa} vanishes at the limit $a \to a_f = a_1\sqrt{1-K_0}$. One has $a_f \simeq a_1$ in excellent approximation for cosmic values of a_1 as is clear from the definition of K_0. For $a = a_f$ the signature of the metric transforms to Euclidian. The relationship between cosmic proper time $t = \int \sqrt{g_{aa}}da$ and a is given in excellent approximation $a = t$ so that the situation is very much like for empty Minkowski space. 3-space is flat but there is no expansion with exponential rate as in the case of inflationary cosmologies. The expansion is accelerating since the counterpart of pressure is negative.

The mass density associated with these cosmologies behaves as $\rho \propto 1/a^2$ for very small values of the M^4_+ proper time. The mass in a co-moving volume is proportional to $a/(1-K)$ and goes to zero at the limit $a \to 0$. Thus, instead of Big Bang one has "Silent Whisper" gradually amplifying to Big Bang. The imbedding fails at the limit $a \to a_1$. At this limit energy density becomes infinite. This cosmology can be regarded as a cosmology for which co-moving strings ($\rho \propto 1/a^2$) dominate the mass density as is clear also from the fact that the "pressure" becomes negative at big bang ($p \to -\rho/3$) reflecting the presence of the string tension. The natural interpretation is that cosmic strings condense on the space-time sheet which is originally empty.

The facts that the imbedding fails and gravitational energy density diverges for $a = a_1$ necessitates a transition to a hyperbolic cosmology. For instance, a transition to radiation or matter dominated hyperbolic cosmology can occur at the limit $\theta \to \pi/2$. At this limit $\phi(r)$ must transform to a function $\phi(a)$. The fact, that vacuum extremals of Kähler action are in question, allows large flexibility for the modelling of what happens in this transition. Quantum criticality and p-adic fractality suggest the presence of an entire fractal hierarchy of space-time sheets representing critical cosmologies created at certain values of cosmic time and having as their light cone projection sub-light cone with its tip at some a=constant hyperboloid.

2.1.4 More general imbeddings of critical and over-critical cosmologies as vacuum extremals

In order to obtain imbeddings as more general vacuum extremals, one must pose the condition guaranteeing the vanishing of corresponding the induced Kähler form (see the Appendix of this book). Using coordinates $(r, u = cos(\Theta), \Psi, \Phi)$ for CP_2 the surfaces in question can be expressed as

$$\begin{aligned}
r &= \sqrt{\frac{X}{1-X}} \ , \\
X &= D|k+u| \ , \\
u &\equiv cos(\Theta) \ , \ D = \frac{r_0^2}{1+r_0^2}\times\frac{1}{C} \ , \quad C = |k+cos(\Theta_0)| \ .
\end{aligned} \tag{2.12}$$

Here C and D are integration constants.

These imbeddings generalize to imbeddings to $M^4 \times Y^2$, where Y^2 belongs to a family of Lagrange manifolds described in the Appendix of this book with induced metric

$$\begin{aligned}
ds^2_{eff} &= \frac{R^2}{4}[s^{eff}_{\Theta\Theta}d\Theta^2 + s^{eff}_{\Phi\Phi}d\Phi^2] \ , \\
s^{eff}_{\Theta\Theta} &= X\times\left[\frac{(1-u^2)}{(k+u)^2}\times\frac{1}{1-X}+1-X\right] \ , \\
s^{eff}_{\Phi\Phi} &= X\times\left[(1-X)(k+u)^2+1-u^2\right] \ .
\end{aligned} \tag{2.13}$$

For $k \neq 1$ $u = \pm 1$ corresponds in general to circle rather than single point as is clear from the fact that $s^{eff}_{\Phi\Phi}$ is non-vanishing at $u = \pm 1$ so that u and Φ parameterize a piece of cylinder. The generalization of the previous imbedding is as

$$sin(\Theta) = ka \quad \rightarrow \quad \sqrt{s^{eff}_{\Phi\Phi}} = ka \ . \tag{2.14}$$

For Φ the expression is as in the previous case and determined by the requirement that g_{rr} corresponds to $k = 0, 1$.

The time component of the metric can be expressed as

$$g_{aa} \quad = \quad 1 - \frac{R^2k^2}{4} \frac{s^{eff}_{\Theta\Theta}}{\frac{d\sqrt{s^{eff}_{\Phi\Phi}}}{d\Theta}} \tag{2.15}$$

In this case the $1/(1-k^2a^2)$ singularity of the density of gravitational mass at $\Theta = \pi/2$ is shifted to the maximum of $s^{eff}_{\Phi\Phi}$ as function of Θ defining the maximal value a_{max} of a for which the imbedding exists at all. Already for $a_0 < a_{max}$ the vanishing of g_{aa} implies the non-physicality of the imbedding since gravitational mass density becomes infinite.

The geometric properties of critical cosmology change radically in the transition to the radiation dominated cosmology: before the transition the CP_2 projection of the critical cosmology is two-dimensional. After the transition it is one-dimensional. Also the isometry group of the cosmology changes from $SO(3) \times E^3$ to $SO(3,1)$ in the transition. One could say that critical cosmology represents Galilean Universe whereas hyperbolic cosmology represents Lorentzian Universe.

2.1.5 String dominated cosmology

A particularly interesting cosmology string dominated cosmology with very nearly critical mass density. Assuming that strings are co-moving the mass density of this cosmology is proportional to $1/a^2$ instead of the $1/a^3$ behavior characteristic to the standard matter dominated cosmology. The line element of this metric is very simple: the time component of the metric is simply constant smaller than 1:

$$g_{aa} \quad = \quad K < 1 \ . \tag{2.16}$$

The Hubble constant for this cosmology is given by

$$H \quad = \quad \frac{1}{\sqrt{K}a} \ , \tag{2.17}$$

and the so called acceleration parameter [E27] k_0 proportional to the second derivative $\ddot{a}$ therefore vanishes. Mass density and pressure are given by the expression

$$\rho \quad = \quad \frac{3}{8\pi GKa^2}(1-K) = -3p \ . \tag{2.18}$$

What makes this cosmology so interesting is the absence of the horizons. The comparison with the critical cosmology shows that these two cosmologies resemble each other very closely and both could be used as a model for the very early cosmology.

2.1.6 Stationary cosmology

An interesting candidate for the asymptotic cosmology is stationary cosmology for which gravitational four-momentum currents (and also gravitational color currents) are conserved. This cosmology extremizes the Einstein-Hilbert action with cosmological term given by $\int (kR+\lambda)\sqrt{g}d^4x + \lambda$ and is obtained as a sub-manifold $X^4 \subset M^4_+ \times S^1$, where S^1 is the geodesic circle of CP_2 (note that imbedding is now unique apart from isometries by variational principle).

For a vanishing cosmological constant, field equations reduce to the conservation law for the isometry associated with S^1 and read

$$\partial_a(G^{aa}\partial_a\phi\sqrt{g}) = 0 \ , \tag{2.19}$$

where ϕ denotes the angle coordinate associated with S^1. From this one finds for the relevant component of the metric the expression

$$\begin{aligned} g_{aa} &= \frac{(1-2x)}{(1-x)} \ , \\ x &= (\frac{C}{a})^{2/3} \ . \end{aligned} \tag{2.20}$$

The mass density and "pressure" of this cosmology are given by the expressions

$$\begin{aligned} \rho &= \frac{3}{8\pi G a^2}\frac{x}{(1-2x)} \ , \\ p &= -(\rho + \frac{a\partial_a \rho}{3}) = -\frac{\rho}{9}\left[3 - \frac{2}{(1-2x)}\right] \ . \end{aligned} \tag{2.21}$$

The asymptotic behavior of the energy density is $\rho \propto a^{-8/3}$. "Pressure" becomes negative indicating that this cosmology is dominated by the string like objects, whose string tension gives negative contribution to to the "pressure". Also this cosmology is horizon free as are all string dominated cosmologies: this is of crucial importance in TGD inspired cosmology.

It should be noticed that energy density for this cosmology becomes infinite for $x = (C/a)^{2/3} = 1/2$ implying that this cosmology doesn't make sense at very early times so that the non-conservation of gravitational energy is necessary during the early stages of the cosmology.

Stationary cosmologies could define space-time correlates for macroscopic quantum states in cosmological length scales predicted by the hypothesis for the values of gravitational Planck constant [K12]. Together with critical cosmologies serving as space-time correlates for cosmic quantum jumps increasing gravitational Planck constant they could define basic building blocks for late cosmologies in TGD Universe.

2.1.7 Non-conservation of gravitational energy in RW cosmologies

In *RW* cosmology the gravitational energy in a given co-moving sphere of radius r in local light cone coordinates (a, r, θ, ϕ) is given by

$$E = \int \rho g^{aa}\partial_a m^0 \sqrt{g} dV \ . \tag{2.22}$$

The rate characterizing the non-conservation of gravitational energy is determined by the parameter X defined as

$$X \equiv \frac{(dE/da)_{vap}}{E} = \frac{(dE/da + \int |g^{rr}| p\partial_r m^0 \sqrt{g} d\Omega)}{E} \ , \tag{2.23}$$

where p denotes the pressure and $d\Omega$ denotes angular integration over a sphere with radius r. The latter term subtracts the energy flow through the boundary of the sphere.

The generation of the pairs of positive and negative (inertial) energy space-time sheets leads to a non-conservation of gravitational energy. The generation of pairs of positive and negative energy cosmic strings would be involved with the generation of a critical sub-cosmology. "Fermionic" pairs would have time-like separation and "bosonic" pairs would consist of parallel stringy space-time sheets connected by wormhole contacts.

For *RW* cosmology with subcritical mass density the calculation gives

$$X = \frac{\partial_a(\rho a^3/\sqrt{g_{aa}})}{(\rho a^3/\sqrt{g_{aa}})} + \frac{3pg_{aa}}{\rho a} \ . \tag{2.24}$$

This formula applies to any infinitesimal volume. The rate doesn't depend on the details of the imbedding (recall that practically any one-dimensional sub-manifold of CP_2 defines a huge family of subcritical cosmologies). Apart from the numerical factors, the rate behaves as $1/a$ in the most physically interesting RW cosmologies. In the radiation dominated and matter dominated cosmologies one has $X = -1/a$ and $X = -1/2a$ respectively so that gravitational energy decreases in radiation and matter dominated cosmologies. For the string dominated cosmology with $k = -1$ having $g_{aa} = K$ one has $X = 2/a$ so that gravitational energy increases: this might be due to the generation of dark matter due to pairs of cosmic strings with vanishing net inertial energy.

For the cosmology with exactly critical mass density Lorentz invariance is broken and the contribution of the rate from 3-volume depends on the position of the co-moving volume. Taking the limit of infinitesimal volume one obtains for the parameter X the expression

$$\begin{aligned} X &= X_1 + X_2 \ , \\ X_1 &= \frac{\partial_a(\rho a^3/\sqrt{g_{aa}})}{(\rho a^3/\sqrt{g_{aa}})} \ , \\ X_2 &= \frac{pg_{aa}}{\rho a} \times \frac{3+2r^2}{(1+r^2)^{3/2}} \ . \end{aligned} \tag{2.25}$$

Here r refers to the position of the infinitesimal volume. Simple calculation gives

$$\begin{aligned} &X = X_1 + X_2 \ , \\ &X_1 = \frac{1}{a}\left[1 + 3K_0u^2\frac{1}{1-K}\right] \ , \\ &X_2 = -\frac{1}{3a}\left[1 - K - \frac{2K_0u^2}{(1-u^2)^2}\right] \times \frac{3+2r^2}{(1+r^2)^{3/2}} \ , \\ &\quad K = \frac{K_0}{1-u^2} \ , \quad u = \frac{a}{a_0} \ , \quad K_0 = \frac{R^2}{4a_0^2} \ . \end{aligned} \tag{2.26}$$

The positive density term X_1 corresponds to increase of gravitational energy which is gradually amplified whereas pressure term ($p < 0$) corresponds to a decrease of gravitational energy changing however its sign at the limit $a \rightarrow a_0$.

The interpretation might be in terms of creation of pairs of positive and negative energy particles contributing nothing to the inertial energy but increasing gravitational energy. Also pairs of positive energy gravitons and negative anti-gravitons are involved. The contributions of all particle species are determined by thermal arguments so that gravitons should not play any special role as thought originally.

Pressure term is negligible at the limit $r \rightarrow \infty$ so that topological condensation occurs all the time at this limit. For $a \rightarrow 0, r \rightarrow 0$ one has $X > 0 \rightarrow 0$ so that condensation starts from zero at $r = 0$. For $a \rightarrow 0, r \rightarrow \infty$ one has $X = 1/a$ which means that topological condensation is present already at the limit $a \rightarrow 0$.

Both the existence of the finite limiting temperature and of the critical mass density imply separately finite energy per co-moving volume for the condensate at the very early stages of the cosmic evolution. In fact, the mere requirement that the energy per co-moving volume in the vapor phase remains finite and non-vanishing at the limit $a \rightarrow 0$ implies string dominance as the following argument shows.

Assuming that the mass density of the condensate behaves as $\rho \propto 1/a^{2(1+\alpha)}$ one finds from the expression

$$\rho \propto \frac{(\frac{1}{g_{aa}} - 1)}{a^2} \ ,$$

that the time component of the metric behaves as $g_{aa} \propto a^{\alpha}$. Unless the condition $\alpha < 1/3$ is satisfied or equivalently the condition

$$\rho \quad < \quad \frac{k}{a^{2+2/3}} \tag{2.27}$$

is satisfied, gravitational energy density is reduced. In fact, the limiting behavior corresponds to the stationary cosmology, which is not imbeddable for the small values of the cosmic time. For stationary cosmology gravitational energy density is conserved which suggests that the reduction of the density of cosmic strings is solely due to the cosmic expansion.

2.2 Cosmic Strings And Cosmology

The model for cosmic strings has forced to question all cherished assumptions including positive energy ontology, Equivalence Principle, and positivity of gravitational mass. The final outcome turned out to be rather conservative. Zero energy ontology is unavoidable, Equivalence Principle holds true universally but its general relativistic formulation makes sense only in long length scales, and gravitational mass has definite sign for positive/negative energy states. As a matter fact, all problems were created by the failure to realize that the expression of gravitational energy in terms of Einstein's tensor does not hold true in short length scales and must be replaced with the stringy expression resulting naturally by dimensional reduction of quantum TGD to string model like theory [K23, K12, K2].

The realization that GRT is only an effective description of many-sheeted space-time as Minkowski space M^4 endowed with effective metric whose deviation from flat metric is the sum of the corresponding deviations for space-time sheets in the region of M^4 considered resolved finally the problems and allowed to reduced Equivalence Principle to its form in GRT. Similar description applies also to gauge interactions.

TGD is therefore a microscopic theory and the physics for single space-time sheet is expected to be extremely simpler, much simpler than in gauge theory and general relativity already due to the fact that only four bosonic variables (4 imbedding space coordinates) defined the dynamics at this level.

2.2.1 Zero energy ontology and cosmic strings

There are two kinds of cosmic strings: free and topological condensed ones and both are important in TGD inspired cosmology.

1. Free cosmic strings are not absolute minima of the Kähler action (the action has wrong sign). In the original identification of preferred extremals as absolute minima of Kähler action this was a problem. In the new formulation preferred extremals correspond to quantum criticality identified as the vanishing of the second variation of Kähler action at least for the deformations defining symmetries of Kähler action [K23, K12]. The symmetries very probably correspond to conformal symmetries acting as or almost as gauge symmetries. The number of conformal equivalence classes of space-time sheets with same Kähler action and conserved charges is expected to be finite and correspond to n in $h_{eff} = n \times h$ defining the hierarchy of Planck constants labelling phases of dark matter (see **Fig.** `http://tgdtheory.fi/appfigures/planckhierarchy.jpg` or **Fig. ??** in the appendix of this book).

   Criticality guarantees the conservation of the Noether charges assignable to the Kähler-Dirac action. Ideal cosmic strings are excluded because they fail to satisfy the conditions characterizing the preferred extremal as a space-time surface containing regions with both Euclidian and Minkowskian signature of the induced metric with light-like 3-surface separating them identified as orbits of partonic 2-surfaces carrying elementary particle quantum numbers. The topological condensation of CP_2 type vacuum extremals representing fermons generates negative contribution to the action and reduces the string tension and leaves cosmic strings still free.

2. If the topologically condensate of fermions has net Kähler charges as the model for matter antimatter asymmetry suggests, the repulsive interaction of the particles tends to thicken the

cosmic string by increasing the thickness of its infinitely thin M^4 projection so that Kähler magnetic flux tubes result. These flux tubes are ideal candidates for the carriers of dark matter with a large value of Planck constant. The criterion for the phase transition increasing $\hbar$ is indeed the presence of a sufficiently dense plasma implying that perturbation theory in terms of $Z^2\alpha_{em}$ (Z is the effective number of charges with interacting with each other without screening effects) fails for the standard value of Planck constant. The phase transition $\hbar_0 \rightarrow \hbar$ reduces the value of $\alpha_{em} = e^2/4\pi\hbar$ so that perturbation theory works. This phase transition scales up also the transversal size of the cosmic string. Similar criterion works also for other charges. The resulting phase is anyonic if the resulting 2-surfaces containing almost spherical portions connected by flux tubes to each other encloses the tip of the causal diamond (CD). The proposal is that dark matter resides on complex anyonic 2-surfaces surrounding the tips of CDs.

3. The topological condensation of cosmic strings generates wormhole contacts represented as pieces of CP_2 type vacuum extremals identified as bosons composed of fermion-anti-fermion pairs. Also this generates negative action and can make cosmic string a preferred extremal of Kähler action. The earliest picture was based on dynamical cancelation mechanism involving generation of strong Kähler electric fields in the condensation whose action compensated for Kähler magnetic action. Also this mechanism might be at work. Cosmic strings could also form bound states by the formation graviton like flux tubes connecting them and having wormhole contacts at their ends so that again action is reduced.

4. One can argue that in long enough length and time scales Kähler action per volume must vanish so that the idealization of cosmology as a vacuum extremal becomes possible and there must be some mechanism compensating the positive action of the free cosmic strings. The general mechanism could be topological condensation of fermions and creation of bosons by topological condensation of cosmic strings to space-time sheets.

In this framework zero energy states correspond to cosmologies leading from big bang to big crunch separated by some time interval T of geometric time. Quantum jumps can gradually increase the value T and TGD inspired theory of consciousness suggests that the increase of T might relate to the shift for the contents of conscious experience towards geometric future. In particular, what is usually regarded as cosmology could have started from zero energy state with a small value of T.

2.2.2 Topological condensation of cosmic strings

In the original vision about topological condensation of cosmic strings I assumed that large voids represented by space-time sheets contain "big" cosmic string in their interior and galactic strings near their boundaries. The recent much simpler view is that there are just galactic strings which carry net fermion numbers (matter antimatter asymmetry). If they have also net em charge they have a repulsive interaction and tend to end up to the boundaries of the large void. Since this slows down the expansive motion of strings, the repulsive interaction energy increases and a phase transition increasing Planck constant and scaling up the size of the void occurs after which cosmic strings are again driven towards the boundary of the resulting larger void.

One cannot assume that the exterior metric of the galactic strings is the one predicted by assuming General Relativity in the exterior region. This would mean that metric decomposes as $g = g_2(X^2) + g_2(Y^2)$. $g(X^2)$ would be flat as also $g_2(Y^2)$ expect at the position of string. The resulting angle defect due to the replacement of plane Y^2 with cone would be large and give rise to lense effect of same magnitude as in the case of GUT cosmic strings. Lense effect has not been observed.

This suggests that General Relativity fails in the length scale of large void as far as the description of topologically condensed cosmic strings is considered. The constant velocity spectrum for distant stars of galaxies and the fact that galaxies are organized along strings suggests that these string generate in a good approximation Newtonian potential. This potential predicts constant velocity spectrum with a correct value velocity.

In the stationary situation one expects that the exterior metric of galactic string corresponds to a small deformation of vacuum extremal of Kähler action which is also extremal of the curvature scalar in the induced metric. This allows a solution ansatz which conforms with Newtonian intuitions and for which metric decomposes as $g = g_1 + g_3$, where g_1 corresponds to axis in the direction of string and g_3 remaining $1 + 2$ directions.

2.2.3 Dark energy is replaced with dark matter in TGD framework

The observed accelerating expansion of the Universe has forced to introduce the notion of cosmological constant in the GRT based cosmology. In TGD framework the situation is different.

1. The gigantic value of gravitational Planck constant implies that dark matter makes TGD Universe a macroscopic quantum system even in cosmological length scales. Astrophysical systems become stationary quantum systems which participate in cosmic expansion only via quantum phase transitions increasing the value of gravitational Planck constant.

2. Critical cosmologies, which are determined apart from a single parameter in TGD Universe, are natural during all quantum phase transitions, in particular the phase transition periods increasing the size of large voids and having interpretation in terms of an increase of gravitational Planck constant. Cosmic expansion is predicted to be accelerating during these periods. The mere criticality requires that besides ordinary matter there is a contribution $\Omega_\Lambda \simeq .74$ to the mass density besides visible matter and dark matter. In fact, also for the over-critical cosmologies expansion is accelerating.

3. In GRT framework the essential characteristic of dark energy is its negative pressure. In TGD framework critical and over-critical cosmologies have automatically effective negative pressure. This is essentially due to the constraint that Lorentz invariant vacuum extremal of Kähler action is in question. The mysterious negative pressure would be thus a signal about the representability of space-time as 4-surface in H and there is no need for any microscopic description in terms of exotic thermodynamics.

2.2.4 The values for the TGD counterpart of cosmological constant

One can introduce a parameter characterizing the contribution of dark mass to the mass density during critical periods and call it cosmological constant recalling however that the contribution does not correspond to dark energy. The value of this parameter is same as in the standard cosmology from mere criticality assumption.

What is new that p-adic fractality predicts that Λ scales as $1/L^2(k)$ as a function of the p-adic scale characterizing the space-time sheet implying a series of phase transitions reducing Λ. The order of magnitude for the recent value of the cosmological constant comes out correctly. The gravitational energy density assignable to the cosmological constant is identifiable as that associated with topologically condensed cosmic strings and magnetic flux tubes to which they are gradually transformed during cosmological evolution.

The naive expectation would be the density of cosmic strings would behave as $1/a^2$ as function of M^4_+ proper time. The vision about dark matter as a phase characterized by gigantic Planck constant however implies that large voids do not expand in continuous manner during cosmic evolution but in discrete quantum jumps increasing the value of the gravitational Planck constant and thus increasing the size of the large void as a quantum state. Since the set of preferred values of Planck constant is closed under multiplication by powers of 2, p-adic length scales L_p, $p \simeq 2^k$ form a preferred set of sizes scales for the large voids.

2.2.5 TGD cosmic strings are consistent with the fluctuations of CMB

GUT cosmic strings were excluded by the fluctuation spectrum of the CMB background [E3]. In GRT framework these fluctuations can be classified to adiabatic density perturbations and isocurvature density perturbations. Adiabatic density perturbations correspond to overall scaling of various densities and do not affect the vanishing curvature scalar. For isocurvature density fluctuations the net energy density remains invariant. GUT cosmic strings predict isocurvature density perturbations while inflationary scenario predicts adiabatic density fluctuations.

In TGD framework inflation is replaced with quantum criticality of the phase transition period leading from the cosmic string dominated phase to matter dominated phase. Since curvature scalar vanishes during this period, the density perturbations are indeed adiabatic.

2.2.6 Matter-antimatter asymmetry and cosmic strings

Despite huge amount of work done during last decades (during the GUT era the problem was regarded as being solved!) matter-antimatter asymmetry remains still an unresolved problem of cosmology. A possible resolution of the problem is matter-antimatter asymmetry in the sense that cosmic strings contain antimatter and their exteriors matter. The challenge would be to understand the mechanism generating this asymmetry. The vanishing of the net gauge charges of cosmic string allows this symmetry since electro-weak charges of quarks and leptons can cancel each other.

The challenge is to identify the mechanism inducing the CP breaking necessary for the matter-antimatter asymmetry. Quite a small CP breaking inside cosmic strings would be enough.

1. The key observation is that vacuum extremals as such are not physically acceptable: small deformations of vacuum extremals to non-vacua are required. This applies also to cosmic strings since as such they do note present preferred extremals. The reason is that the preferred extremals involve necessary regions with Euclidian signature providing four-dimensional representations of generalized Feynman diagrams with particle quantum numbers at the light-like 3-surfaces at which the induced metric is degenerate.

2. The simplest deformation of vacuum extremals and cosmic strings would be induced by the topological condensation of CP_2 type vacuum extremals representing fermions. The topological condensation at larger space-time surface in turn creates bosons as wormhole contacts.

3. This process induces a Kähler electric fields and could induce a small Kähler electric charge inside cosmic string. This in turn would induce CP breaking inside cosmic string inducing matter antimatter asymmetry by the minimization of the ground state energy. Conservation of Kähler charge in turn would induce asymmetry outside cosmic string and the annihilation of matter and antimatter would then lead to a situation in which there is only matter.

4. Either galactic cosmic strings or big cosmic strings (in the sense of having large string tension) at the centers of galactic voids or both could generate the asymmetry and in the recent scenario big strings are not necessary. One might argue that the photon to baryon ratio $r \sim 10^{-9}$ characterizing matter asymmetry quantitatively must be expressible in terms of some fundamental constant possibly characterizing cosmic strings. The ratio $\epsilon = G/\hbar R^2 \simeq 4 \times 10^{-8}$ is certainly a fundamental constant in TGD Universe. By replacing R with $2\pi R$ would give $\epsilon = G/(2\pi R)^2 \simeq 1.0 \times 10^{-9}$. It would not be surprising if this parameter would determine the value of r.

The model can be criticized.

1. The model suggest only a mechanism and one can argue that the Kähler electric fields created by topological condensates could be random and would not generate any Kähler electric charge. Also the sign of the asymmetry could depend on cosmic string. A CP breaking at the fundamental level might be necessary to fix the sign of the breaking locally.

2. The model is not the only one that one can imagine. It is only required that antimatter is somewhere else. Antimatter could reside also at other p-adic space-time sheets and at the dark space-time sheets with different values of Planck constant.

The needed CP breaking is indeed predicted by the fundamental formulation of quantum TGD in terms of the Kähler-Dirac action associated with Kähler action and its generalization allowing include instanton term as imaginary part of Kähler action inducing CP breaking [K23, K17] .

1. The key idea in the formulation of quantum TGD in terms of modified Dirac equation associated with Kähler action is that the Dirac determinant defined by the generalized eigenvalues assignable to the Dirac operator D_K equals to the vacuum functional defined as the exponent of Kähler function in turn identifiable as Kähler action for a preferred extremal, whose proper identification becomes a challenge. In ZEO (ZEO) 3-surfaces are pairs of space-like 3-surfaces assignable to the boundaries of causal diamond (CD) and for deterministic action principle this suggests that the extremals are unique. In presence of non-determinism the situation changes.

2. The huge vacuum degeneracy of Kähler action suggests that for given pair of 3-surfaces at the boundaries of CD there is a continuum of extremals with the same Kähler action and conserved charges obtained from each other by conformal transformations acting as gauge symmetries and respecting the light-likeness of wormhole throats (as well as the vanishing of the determinant of space-time metric at them). The interpretation is in terms of quantum criticality with the hierarchy of symmetries defining a hierarchy of criticalities analogous to the hierarchy defined by the rank of the matrix defined by the second derivatives of potential function in Thom's catastrophe theory.

3. The number of gauge equivalence classes is expected to be finite integer n and the proposal is that it corresponds to the value of the effective Planck constant $h_{eff} = n \times h$ so that a connection with dark matter hierarchy labelled by values of n emerges [K11].

4. This representation generalizes - at least formally. One could add an imaginary instanton term to the Kähler function and corresponding Kähler-Dirac operator D_K so that the generalized eigenvalues assignable to D_K become complex. The generalized eigenvalues correspond to the square roots of the eigenvalues of the operator $DD^\dagger = (p^k\gamma_k + \Gamma^n)(p^k\gamma_k + \Gamma^n)^\dagger$ acting at the boundaries of string world sheets carrying fermion modes and it seems that only space-like 3-surfaces contribute. Γ^n is the normal component of the vector defined by Kähler-Dirac gamma matrices. One can define Dirac determinant formally as the product of the eigenvalues of $DD^\dagger$.

   The conjecture is that the resulting Dirac determinant equals to the exponent of Kähler action and imaginary instanton term for the preferred extremal. The instanton term does not contribute to the WCW metric but could provide a first principle description for CP breaking and anyonic effects. It also predicts the dependence of these effects on the page of the book like structure defined by the generalized imbedding space realizing the dark matter hierarchy with levels labeled by the value of Planck constant.

5. In the case of cosmic strings CP breaking could be especially significant and force the generation of Kähler electric charge. Instanton term is proportional to $1/h_{eff}$ so that CP breaking would be small for the gigantic values of h_{eff} characterizing dark matter. For small values of h_{eff} the breaking is large provided that the topological condensation is able to make the CP_2 projection of cosmic string four-dimensional so that the instanton contribution to the complexified Kähler action is non-vanishing and large enough. Since instanton contribution as a local divergence reduces to the contributions assignable to the light-like 3-surfaces X_l^3 representing topologically condensed particles, CP breaking is large if the density of topologically condensed fermions and wormhole contacts generated by the condensation of cosmic strings is high enough.

2.2.7 CP breaking at the level of CKM matrix

The CKM matrix for quarks contains CP breaking phase factors and this could lead to different evaporation rates for baryons and anti-baryons are different (quark cannot appear as vapor phase particle since vapor phase particle must have vanishing color gauge charges and in the recent vision about quantum TGD CP_2 type vacuum extremal which has not suffered topological condensation represents vacuum). The CP breaking at the level of CKM matrix would be implied by the instanton term present in the complexified Kähler action and Kähler-Dirac operator. The mechanism might rely on hadronic Kähler electric fields which are accompanied by color electric gauge fields proportional to induced Kähler form.

The topological condensation of quarks on hadronic strings containing weak color electric fields proportional to Kähler electric fields should be responsible for its string tension and this should in turn generate CP breaking. At the parton level the presence of CP breaking phase factor $exp(ikS_{CS})$, where $S_{CS} = \int_{X^4} J \wedge J + boundary\ term$ is purely topological Chern Simons term and naturally associated with the boundaries of space-time sheets with at most $D = 3$-dimensional CP_2 projection, could have something to do with the matter antimatter asymmetry. Note however that TGD predicts no strong CP breaking as QCD does [K2].

2.2.8 Development of strings in the string dominated cosmology

The development of the string perturbations in the Robertson Walker cosmology has been studied [E4] and the general conclusion seems to be that that all the details smaller than horizon are rapidly smoothed out. One must of course take very cautiously the application of these result in TGD framework.

In present case, the horizon has an infinite size so that details in all scales should die away. To see what actually happens consider small perturbations of a static string along z-axis. Restrict the consideration to a perturbation in the y-direction. Using instead of the proper time coordinate t the "conformal time coordinate" τ defined by $d\tau = dt/a$ the equations of motion read [E4]

$$\begin{aligned} (\partial_\tau + \frac{2\dot{a}}{a})(\dot{y}U) &= \partial_z(y'U) \ , \\ U &= \frac{1}{\sqrt{1+(y')^2-\dot{y}^2}} \ . \end{aligned} \tag{2.28}$$

Restrict the consideration to small perturbations for which the condition $U \simeq 1$ holds. For the string dominated cosmology the quantity $\dot{a}/a = 1/\sqrt{K}$ is constant and the equations of motion reduce to a very simple approximate form

$$\ddot{y} + \frac{2}{\sqrt{K}}\dot{y} - y'' = 0 \ . \tag{2.29}$$

The separable solutions of this equation are of type

$$\begin{aligned} y &= g(a)(C\sin(kz) + D\cos(kz)) \ , \\ g(a) &= (\frac{a}{a_0})^r \ . \end{aligned} \tag{2.30}$$

where r is a solution of the characteristic equation $r^2 + 2r/\sqrt{K} + k^2 = 0$:

$$r = -\frac{1}{\sqrt{K}}(1 \pm \sqrt{1-k^2K}) \ . \tag{2.31}$$

For perturbations of small wavelength $k > 1/\sqrt{K}$, an extremely rapid attenuation occurs; $1/\sqrt{K} \simeq 10^{27}$! For the long wavelength perturbations with $k << 1/\sqrt{K}$ (physical wavelength is larger than t) the attenuation is milder for the second root of above equation: attenuation takes place as $(a/a_0)^{\sqrt{K}k^2/2}$. The conclusion is that irregularities in all scales are smoothed away but that attenuation is much slower for the long wave length perturbations.

The absence of horizons in the string dominated phase has a rather interesting consequence. According to the well known Jeans criterion the size L of density fluctuations leading to the formation of structures [E4] must satisfy the following conditions

$$l_J < L < l_H \ , \tag{2.32}$$

where l_H denotes the size of horizon and l_J denotes the Jeans length related to the sound velocity v_s and cosmic proper time as [E4]

$$l_J \simeq 10 v_s t \ . \tag{2.33}$$

For a string dominated cosmology the size of the horizon is infinite so that no upper bound for the size of the possible structures results. These structures of course, correspond to string like objects of various sizes in the microscopic description. This suggests that primordial fluctuations create structures of arbitrary large size, which become visible at much later time, when cosmology becomes string dominated again.

2.3 Thermodynamical Considerations

The new view about energy challenging the universal applicability of the second law of thermodynamics, the existence of "vapor phase" consisting mainly of cosmic strings and critical temperature equal to Hagedorn temperature are basic characteristics of TGD inspired cosmology. The recent view about preferred extremals cspin, newviews requires that cosmic strings are accompanied by a topological condensate of fermions (and possibly also super-symplectic bosons) represented by CP_2 type vacuum extremals. The corresponding light-like 3-surfaces define generalized Feynman diagram associated with the state.

2.3.1 New view about second law: first trial

Quantum classical correspondence suggests negative and positive energy strings (in the sense of zero energy ontology) tend to dissipate backwards in opposite directions of the geometric time in their geometric degrees of freedom. Time reversed dissipation of negative energy states looks from the point of view of systems consisting of positive energy matter self-organization and even self assembly. The matter at the space-time sheet containing strings in turn consists of positive energy matter and negative energy antimatter and also here same competition would prevail.

This tension suggests a general manner to understand the paradoxical aspects of the cosmic and biological evolution.

1. The first paradox is that the initial state of cosmic evolution seems to correspond to a maximally entropic state. Entropy growth would be naturally due to the emergence of matter inside cosmic strings giving them large p-adic entropy proportional to mass squared [K12, K2]. As strings decay to ordinary matter and transform to magnetic flux tubes the entropy related to translation degrees of freedom increases.

2. The dissipative evolution of matter at space-time sheets with positive time orientation would obey second law and evolution of space-time sheets with negative time orientation its geometric time reversal. Second law would hold true in the standard sense as long as one can neglect the interaction with negative energy antimatter and strings.

3. The presence of the cosmic strings with negative energy and time orientation could explain why gravitational interaction leads to a self-assembly of systems in cosmic time scales. The formation of supernovae, black holes and the possible eventual concentration of positive energy matter at the negative energy cosmic strings could reflect the self assembly aspect due to the presence of negative energy strings. An analog of biological self assembly identified as the geometric time reversal for ordinary entropy generating evolution would be in question.

4. In the standard physics framework the emergence of life requires extreme fine tuning of the parameters playing the role of constants of Nature and the initial state of the Universe should be fixed with extreme accuracy in order to predict correctly the emergence of life. In the proposed framework situation is different. The competition between dissipations occurring in reverse time directions means that the analog of homeostasis fundamental for the functioning of living matter is realized at the level of cosmic evolution. The signalling in both directions of geometric time makes the system essentially four-dimensional with feedback loops realized as geometric time loops so that the evolution of the system would be comparable to the carving of a four-dimensional statue rather than approach to chaos.

5. The apparent creation of order by the gravitational interactions is a mystery in the standard cosmology. A naive application of the second law of thermodynamics suggests that in GRT based cosmology the most probable end state corresponds to a black hole dominated Universe since the entropy of the black hole is much larger than the entropy of a typical star with the same mass. TGD allows to consider several alternative solutions of this puzzle.

   (a) One might think that the the hierarchy of Planck constants and the proportional of the black hole entropy to $\hbar$ could make black holes entropic so that they would not be favored final states of evolution. This argument turned out to be wrong. If black holes are dark black holes with a gigantic gravitational Planck constant the sheets of the blackhole surface for C-C option - which can be understood as a consequence of basic TGD- are not entropic since the entropy for single sheet of the covering is scaled down by $1/n_a n_b$. For the entire covering one however obtains just the standard black-hole entropy since the number of sheets equals to $\hbar/\hbar_0$. This would suggest that entropy serves as a control variable in the sense that when it exceeds the threshold value, the partonic 2-surfaces at the ends of CD split to a surfaces in the covering. In the Bohr orbit model for solar system the value of Planck constant for the space-time sheets mediating gravitational interaction has the gigantic value $\hbar_{gr} = GM_1M_2/v_0$, where $v_0 = 2^{-11}$ holds true for inner planets. If $\hbar_{gr} = GM^2/v_0$ holds true for black holes, black hole entropy for single sheet of covering would be of order $1/v_0$. For $v_0 = 1/4$ this entropy would be of order single bit and Schwartshild radius would be equal to the scaled up Planck length $l_P = \sqrt{\hbar_{gr}}M$.

(b) The new view about second law inspires the view that gravitational self-organization corresponds to the temporal mirror image of dissipative time evolution for space-time sheets with negative time orientation competing with thermalization. In this situation negative energy dark black holes with small entropy are possible. The formation of black hole would look like breaking of second law from the point of view of observed with standard arrow of geometric time. The self organizing tendency of negative energy cosmic strings would compete with the opposite tendency of positive energy strings and ordinary matter could give rise to kind of gravitational homeostasis. Although black-hole like structures would result as outcome of gravitational self-organization they would not be sinks of information but have complex internal information carrying structure.

(c) It is also possible that elementary particles take the role of black holes in TGD framework. CP_2 type extremals are the counterparts of the black holes in TGD. Hawking-Bekenstein area law generalizes and states that elementary particles are carriers of p-adic entropy. Thus this p-adic entropy associated with the thermodynamics of Virasoro generator L_0 could be the counterpart of black hole entropy and the decay of the free cosmic strings to elementary particles would thus generate "invisible" entropy. The upper bound for the p-adic entropy depends on p-adic condensation level as $log(p)$ so that the generation of the new space-time sheets with increasing size (and thus p) generates new entropy since the particles, which are topologically condensed on these sheets, can have entropy of order $log(p)$.

2.3.2 New view about second law: second trial

The proposed new view about second law can be criticized of involving un-necessary assumptions about the details of dynamics. The real understanding of what second law inspired by TGD inspired theory of consciousness [K14] and zero energy ontology indeed allows to resolve the paradox without making this kind of assumptions.

The TGD inspired proposal is based on zero energy ontology and new view about the relationship between subjective and geometric time. In zero energy ontology causal diamonds (CDs) defined as intersections of future and past light-cones of Minkowski space define basic building blocks of world of classical worlds. CDs are thought to have position in M^4 characterized by tips of the light-cones: this guarantees Poincare invariance broken for individual CD. The world of classical worlds is union of sub-worlds of classical worlds defined by space-time surfaces inside given CD. CDs also define a fractal structure: CDs within CDs are possible and the assumption that the temporal distance between tips comes in powers of 2 implies p-adic length scale hypothesis. The hypothesis assigns to elementary particles time scale. For electron this time scale is.1 seconds, which corresponds to 10 Hz biorhythm associated with living systems. p-Adic length scale $L(193) = 2.1$ cm corresponds to $T(193) = 2.4 \times 10^{11}$ years, which gives order of magnitude for the age of the Universe. $L(193) = 2.1$. $L(199) = 16.7$ cm (length scale defined by human brain) corresponds to $T(199) = 1.5 \times 10^{13}$ years which could be regarded as an upper bound for the age of the Universe. Maybe brain hemispheres correspond to cosmological CD.

In TGD inspired theory of consciousness CDs serve as correlates for selves and CD can be identified as perceptive field of self defining the contents of consciousness of self. One can understand the arrow of psychological time emerging as apparent arrow of geometric time [K3]. Also the localization of sensory mental experiences to a narrow time interval instead of entire CD can be understood using same argument. Memories are however distributed to entire CD and this leads to a new view about what memories are.

Consider now the argument.

1. It is *subjective* time with respect to which second law holds true. It corresponds to the geometric time of observer *only locally*.

2. One can apply second law only for to what happens inside 4-D causal diamond (CD) corresponding to the time scale of observations: in positive energy ontology second law is applied at fixed value of geometric time and this leads to problems. In cosmology the relevant CD extends from the moment of big bang and to the recent time or even farther to geometric future. The idea that entropy grows as a function of cosmic time is simply wrong if you accept zero energy ontology.

More concrete picture would look like follows.

1. In each quantum jump re-creating entire 4-D Universe the entire geometric *future* and *past* changes.

2. Initial state of big bang in geometric sense- the zero energy states associated with small CDs near the light-cone boundary corresponding to Big Bang- are replaced by a new one at every moment of subjective time. Hence the "subjectively recent" initial state of Big Bang can be assumed to have maximum entropy as also states after that when the time scale of observations (size of CD) is the age of the universe. Gradually the entire geometric past ends up to a maximum entropy state in time scales below the time scale characterizing the time scale of observations. Thermal equilibrium in 4-D sense rather than 3-D sense results and the paradox disappears.

Note that the breaking of strict classical determinism of Kähler action allowing CDs within CDs picture is essential mathematical prerequisite: otherwise this picture does not make sense. It makes possible also space-time correlates for quantum jump sequence rather than only for quantum states.

2.3.3 Vapor phase

The structure of $M^4_+ \times CP_2$ suggests kinematic constraints on the cosmology: for the very small values of the M^4_+ proper time a the allowed 3-surfaces are necessarily CP_2 type surfaces or string like objects rather than pieces of M^4. As a consequence, topological evaporation should take place so that the space-time resembles enormous stringy diagram containing inside itself generalized Feynman diagram rather than continuous "classical" space-time. It indeed turns out that although the condensate could be present also in the primordial stage, the dominant contribution to the energy density is in the vapor phase during the primordial cosmology (and as it turns out, also in recent cosmology unless one takes into account the fact that at each level of condensate cosmic expansion is only local!).

The properties of the critical cosmology suggest that space-time sheets representing critical sub-cosmologies are generated only after some value $a_0 \sim R$ of light cone proper time, where $R \sim 10^{3.5}$ Planck times corresponds is CP_2 time. Before this moment there would be no macroscopic space-time but only vapor phase consisting of cosmic strings containing topologically condensed fermions and having purely geometric contact interactions. Thus the idea about primordial cosmology as a stage preceding the formation of space-time in the sense of General Relativity seems to be correct in TGD framework.

The key object of the TGD inspired cosmology is cosmic string with string tension $T \simeq .2 \times 10^{-6}/G$ of same order as the string tension of the GUT strings but with totally different physical and geometric interpretation. Cosmic strings play a key role in the very early string dominated cosmology, they could generate the matter antimatter asymmetry, they would lead to the formation of the large voids and galaxies, they would give rise to the galactic dark matter and also dominate the mass density in the asymptotic cosmology. Vapor phase cosmic strings containing dark might be present also in the cosmology of later times and correspond closely to the vacuum energy density of inflationary cosmologies: now however dark matter rather than dark energy would be in question.

For critical cosmology the gravitational energy of the co-moving volume is proportional to a at the limit $a \to 0$ and vanishes so that "Silent Whisper" amplifying to "Big Bang" is in question. The assumption that also vapor phase gravitational energy density (that is density in imbedding space) behaves in similar manner implies the absence of initial singularities also at vapor phase level. Thus the condition

$$\rho \propto \frac{1}{a^2} , \tag{2.34}$$

and hence the string dominated primordial cosmology both in vapor phase and space-time sheets is an attractive hypothesis mathematically. The simplest hypothesis suggested by dimensional considerations is that the mass density of the vapor phase near $a = 0$ behaves as

$$\rho = n\frac{3}{8\pi G a^2} . \tag{2.35}$$

Here n is numerical factor of order one. This hypothesis fixes the total energy density of the universe and sets strong constraints on energetics of the cosmology. At later stages topological condensation of the strings reduces the mass density in vapor phase and replaces n by a decreasing function of a. A very attractive hypothesis is that the value of of n is

$$n = 1 . \tag{2.36}$$

This gravitational energy density is same as that of critical cosmology at the limit of flatness and can be interpreted as TGD counterpart for the basic hypothesis of inflationary cosmologies. In inflationary cosmologies 70 per cent of the critical mass density is in form of vacuum energy deriving from cosmological constant. In TGD the counterpart of vacuum energy could be the mass density of cosmic strings in vapor phase in these sense that it topologically condensed on string like objects. By quantum classical correspondence it however corresponds to dark matter rather than genuine dark energy.

One can criticize the assumption as un-necessarily strong. There is no absolute necessity for the density of gravitational four-momentum of strings in M^4_+ to be conserved and one can consider the possibility that zero inertial energy string pairs are created from vacuum everywhere inside future light cone.

Long range interactions in the vapor phase are generated only by the exchange of particle like 3-surfaces and the long range interactions mediated by the exchange of the boundary components are impossible. The exchange of CP_2 type vacuum extremals has geometric cross section and the same is expected to be true for the other exchanges of the particle like surfaces. This would mean that the interaction cross sections are determined by the size of the particle of the order of CP_2 radius: $\sigma \simeq l^2 \sim 10^8 G$. In this sense the asymptotic freedom of gauge theories would be realized in the vapor phase. It should be emphasized that this assumption might be wrong and that the gauge interactions between two particles belonging to vapor phase and condensate respectively are certainly present and topological condensation can be indeed seen as this interaction. It should be noticed that the expansion of the Universe in vapor phase is slower than in condensed phase: the ratio of the expansion rates of the universe in vapor and condensed phases is given by the velocity of light in the condensed phase ($c_{\#} = \sqrt{g_{aa}}$).

Also the cross sections for the purely geometric contact interactions of free cosmic strings are extremely low. This suggests that vapor phase is in essentially in temperature zero string dominated state and that the energy density of strings behaves as $1/a^2$.

2.3.4 Limiting temperature

Since particles are extended objects in TGD, one expects the existence of the limiting temperature T_H (Hagedorn temperature as it is called in string models) so that the primordial cosmology is in Hagedorn temperature. A special consequence is that the contribution of the light particles to the energy density becomes negligible: this is in accordance with the string dominance of the critical mass cosmology. The value of T_H is of order $T_H \sim \hbar/R$, where R is CP_2 radius of order $R \sim 10^{3.5}\sqrt{G}$ and thus considerably smaller than Planck temperature. Note that T_H increases with Planck constant and one can wonder whether this increase continues only up to $T_H = \hbar_{cr}/R = \sqrt{\hbar_{cr}/G}$, which corresponds to the critical value $\hbar_{cr} = R^2/G$. The value $R^2/G = 3 \times 20^{23}\hbar_0$ is consistent with p-adic mass calculations and is favored by by number theoretical arguments [K12, K2].

The existence of limiting temperature gives strong constraint to the value of the light cone proper time a_F when radiation dominance must have established itself in the critical cosmology which gave rise to our sub-cosmology. Before the moment of transition to hyperbolic cosmology critical cosmology is string dominated and the generation of negative energy virtual gravitons builds up gradually the huge energy density density, which can lead to gravitational collapse, splitting of the strings and establishment of thermal equilibrium with gradually rising temperature. This temperature cannot however become higher than Hagedorn temperature T_H, which serves thus as the highest possible temperature of the effectively radiation dominated cosmology following the critical period. The decay of the split strings generates elementary particles providing the seeds of galaxies.

If most strings decay to light particles then energy density is certainly of the form $1/a^4$ of radiation dominated cosmology. This is not the only manner to obtain effective radiation dominance. Part of the thermal energy goes to the kinetic energy of the vibrational motion of strings and energy density $\rho \propto 1/a^2$ cannot hold anymore. The strings of the condensate is expected to obey the scaling law $\rho \propto 1/a^4$, $p = \rho/3$ [E4]. The simulations with string networks suggest that the energy density of the string network behaves as $\rho \propto 1/a^{2(1+v^2)}$, where v^2 is the mean square velocity of the point of the string [E10]. Therefore, if the value of the mean square velocity approaches light velocity, effective radiation dominance results even when strings dominate [E30]. In radiation dominated cosmology the velocity of sound is $v = 1/\sqrt{3}$. When v lowers to sound velocity one obtains stationary cosmology which is string dominated.

An estimate for a_F is obtained from the requirement that the temperature of the radiation dominated cosmology, when extrapolated from its value $T_R \simeq .3$eV at the time about $a_R \sim 3\times10^7$ years for the decoupling of radiation and matter to $a = a_F$ using the scaling law $T \propto 1/a$, corresponds to Hagedorn temperature. This gives

$$\begin{aligned} a_F &= a_R \frac{T_R}{T_H} \ , \\ T_H &= \frac{n}{R} \ , \qquad a_R \sim 3\times 10^7 \ y \ , \quad T_R = .27 \ eV \ . \end{aligned} \tag{2.37}$$

This gives a rough estimate $a_F \sim 3 \times 10^{-10}$ seconds, which corresponds to length scale of order 7.7×10^{-2} meters. The value of a_F is quite large.

The result does not mean that radiation dominated sub-cosmologies might have not developed before $a = a_F$. In fact, entire series of critical sub-cosmologies could have developed to radiation dominated phase before the final one leading to our sub-cosmology is actually possible. The contribution of sub-cosmology i to the total energy density of recent cosmology is in the first approximation equal to the fraction $(a_F(i)/a_F)^4$. This ratio is multiplied by a ratio of numerical factors telling the number of effectively massless particle species present in the condensate if elementary particles dominate the mass density. If strings dominate the mass density (as expected) the numerical factor is absent.

For some reason the later critical cosmologies have not evolved to the radiation dominated phase. This might be due to the reduced density of cosmic strings in the vapor phase caused by the formation of the earlier cosmologies which does not allow sufficiently strong gravitational collapse to develop and implies that critical cosmology transforms directly to stationary cosmology without the intervening effectively radiation dominated phase. Indeed, condensed cosmic strings develop Kähler electric field compensating the huge positive Kähler action of free string and can survive the decay to light particles if they are not split. The density of split strings yielding light particles is presumably the proper parameter in this respect.

p-Adic length scale hypothesis allows rather predictive quantitative model for the series of sub-cosmologies [K18] predicting the number of them and allowing to estimate the moments of their birth, the durations of the critical periods and also the durations of radiation dominated phases. p-Adic length scale hypothesis allows also to estimate the maximum temperature achieved during the critical period: this temperature depends on the duration of the critical period a_1 as $T \sim n/a_1$, where n turns out to be of order 10^{30}. This means that if the duration of the critical period is long enough, transition to string dominated asymptotic cosmology occurs with the intervening decay of cosmic strings leading to the radiation dominated phase.

The existence of the limiting temperature has radical consequences concerning the properties of the very early cosmology. The contribution of a given massless particle to the energy density becomes constant. So, unless the number of the effectively massless particle families $N(a)$ increases too fast the contribution of the effectively massless particles to the energy density becomes negligible. The massive excitations of large size (string like objects) are indeed expected to become dominant in the mass density.

2.3.5 What about thermodynamical implications of dark matter hierarchy?

The previous discussion has not mentioned dark matter hierarchy labeled by increasing values of Planck constants and predicted macroscopic quantum coherence in arbitrarily long scales. In TGD Universe dark matter hierarchy means also a hierarchy of conscious entities with increasingly long span of memory and higher intelligence [K20, K8].

This forces to ask whether the second law is really a fundamental law and whether it could reflect a wrong view about existence resulting resulting when all these dark matter levels and information associated with conscious experiences at these levels is neglected. For instance, biological evolution difficult to understand in a universe obeying second law relies crucially on evolution as gradual progress in which sudden leaps occur as new dark matter levels emerge.

TGD inspired consciousness suggests that Second Law holds true only for the mental images of a given self (a system able to avoid bound state entanglement with environment [K20]) rather than being a universal physical law. Besides these mental images there is irreducible basic awareness of self and second law does not apply to it. Also the hierarchy of higher level conscious entities is there. In this framework second law would basically reflect the exclusion of conscious observers from the physical model of the Universe.

2.4 Structure Of WCW In Zero Energy Ontology And Robertson-Walker Cosmology

Zero energy ontology has meant a real quantum leap in the understanding of the exact structure of the world of classical worlds (WCW). There are however still open questions and interpretational problems. The following comments are about a quantal interpretation of Robertson-Walker cosmology provided by zero energy ontology.

1. The light-like 3-surfaces -or equivalently corresponding space-time sheets- inside a particular causal diamond (CD) is the basic structural unit of world of classical worlds (WCW)). CD (or strictly speaking $CD \times CP_2$) is characterized by the positions of the tips for the intersection of the future and past directed light-cones defining it. The Lorentz invariant temporal distance a between the tips allows to characterize the CDs related by Lorentz boosts and $SO(3)$ acts as the isotropy group of a given CD. CDs with a given value of a are parameterized by Lobatchevski space -call it $L(a)$- identifiable as $a^2 = constant$ hyperboloid of the future light-cone and having interpretation as a constant time slice in TGD inspired cosmology.

2. The moduli space for CDs characterized by a given value of a is $M^4 \times L(a)$. If one poses no restrictions on the values of a, the union of all CDs corresponds to $M^4 \times M^4_+$, where M^4_+ corresponds to the interior of future light-cone. F-theorist might get excited about dimension 12 for $M^4 \times M^4_+ \times CP_2$: this is of course just a numerical co-incidence.

3. p-Adic length scale hypothesis follows if it is assumed that a comes as octaves of CP_2 time scale: $a_n = 2^n T_{CP_2}$. For this option the moduli space would be discrete union $\cup_n M^4 \times L(a_n)$. A weaker condition would be that a comes as prime multiples of T_{CP_2}. In this case the preferred p-adic primes $p \simeq 2^n$ correspond to $a = a_n$ and would be natural winners in fight

for survival. If continuum is allowed, p-adic length scale hypothesis must be be a result of dynamics alone. Algebraic physics favors quantization at the level of moduli spaces.

4. Also unions of CDs are possible. The proposal has been that CDs form a fractal hierarchy in the sense that there are CDs within CDs but that CDs to not intersect. A more general option would allow also intersecting CDs.

Consider now the possible cosmological implications of this picture. In TGD framework Robertson-Walker cosmologies correspond to Lorentz invariant space-time surfaces in M^4_+ and the parameter a corresponds to cosmic time.

1. First some questions. Could Robertson Walker coordinates label CDs rather than points of space-time surface at deeper level? Does the parameter a labeling CDs really correspond to cosmic time? Do astrophysical objects correspond to sub-CDs?

2. An affirmative answer to these questions is consistent with classical causality since the observer identified as -say- upper boundary of CD receives classical positive/negative energy signals from sub-CDs arriving with a velocity not exceeding light-velocity. $M^4 \times L(a)$ decomposition provides also a more precise articulation of the answer to the question how the non-conservation of energy in cosmological scales can be consistent with Poincare invariance. Note also that the empirically favored sub-critical Robertson-Walker cosmologies are unavoidable in this framework whereas the understanding of sub-criticality is one of the fundamental open problems in General Relativity inspired cosmology.

3. What objections against this interpretation can one imagine?

   (a) Robertson-Walker cosmology reduces to future light-cone only at the limit of vanishing density of gravitational mass. One could however argue that the scaling factor of the metric of $L(a)$ need not be a^2 corresponding to M^4_+ but can be more general function of a. This would allow all Robertson-Walker cosmologies with sub-critical mass density. This argument makes sense also for $a = a_n$ option.

   (b) Lorentz invariant space-time surfaces in CD provide an elegant and highly predictive model for cosmology. Should one give up this model in favor of the proposed model? This need not to be the case. Quantum classical correspondence requires that also the quantum cosmology has a representation at space-time level.

4. What is then the physical interpretation for the density of gravitational mass in Robertson-Walker cosmology in the new framework? A given CD characterized by a point of $M^4 \times L(a)$, has certainly a finite gravitational mass identified as the mass assignable to positive/negative energy state at either upper or lower light-like boundary or CD. In zero energy ontology this mass is actually an average over a superposition of pairs of positive and negative energy states with varying energies. Since quantum TGD can be seen as square root of thermodynamics the resulting mass has only statistical meaning. One can assign a probability amplitude to CD as a wave function in $M^4 \times L(a)$ as a function of various quantum numbers. The cosmological density of gravitational mass would correspond to the quantum average of the mass density determined by this amplitude. Hence the quantum view about cosmology would be statistical as is also the view provided by standard cosmology.

5. Could cosmological time be really quantized as $a = a_n = 2^n T(CP_2)$? Note that other values of a are possible at the pages of the book like structure representing the generalized imbedding space since a scales as $r = \hbar/\hbar_0$ at these pages. All rational multiples of a_n are possible for the most general option. The quantization of a does not lead to any obvious contradiction since M^4 time would correspond to the time measured in laboratory and there is no clock keeping count about the flow of a and telling whether it is really discrete or continuous. It might be however possible to deduce experimental tests for this prediction since it holds true in all scales. Even for elementary particles the time scale a is macroscopic. For electron it is.1 seconds, which defines the fundamental bio-rhythm.

6. The quantization for a encourages also to consider the quantization for the space of Lorentz boosts characterized by $L(a)$ obtained by restricting the boosts to a subgroup of Lorentz group. A more concrete picture is obtained from the representation of $SL(2,C)$ as Möbius transformations of plane [A2].

   (a) The restriction to a discrete subgroup of Lorentz group $SL(2,C)$ is possible. This would allow an extremely rich structure. The most general discrete subgroup would be subgroup of $SL(2,Q_C)$, where Q_C could be any algebraic extension of complex rational numbers. In particular, discrete subgroups of rotation group and powers L^n of a basic Lorentz boost $L = exp(\eta_0)$ to a motion with a fixed velocity $v_0 = tanh(\eta_0)$ define lattice like structures in $L(a)$. This would effectively mean a cosmology in 4-D lattice. Note that everything is fully consistent with the basic symmetries.

   (b) The alternative possibility is that all points of $L(a)$ are possible but that the probability amplitude is invariant under some discrete subgroup of $SL(2,Q_C)$. The first option could be seen as a special case of this.

   (c) One can consider also the restriction to a discrete subgroup of $SL(2,R)$ known as Fuschian groups Fuschian. This would mean a spontaneous breaking of Lorentz symmetry since only boosts in one particular direction would be allowed. The modular group $SL(2,Z)$ and its subgroups known as congruence subgroups [?] define an especially interesting hierarchy of groups if this kind: the tesselations of hyperbolic plane provide a concrete representation for the resulting hyperbolic geometries.

   (d) Is there any experimental support for these ideas. There are indeed claims for the quantization of cosmic recession velocities of quasars [E19] discussed in [K7] in terms of TGD inspired classical cosmology. For non-relativistic velocities this means that in a given direction there are objects for which corresponding Lorentz boosts are powers of a basic boost $exp(\eta_0)$. The effect could be due to a restriction of allowed Lorentz boosts to a discrete subgroup or to the invariance of the cosmic wave function under this kind of subgroup. These effects should take place in all scales: in particle physics they could manifest themselves as a periodicity of production rates as a function of η closely related to the so called rapidity variable y.

7. The possibility of CDs would mean violent collisions of sub-cosmologies. One could consider a generalized form of Pauli exclusion principle denying the intersections.

2.5 Is Cosmic Expansion A Mere Coordinate Effect?

There is a very interesting article about cosmic expansion or rather a claim about the possible absence of cosmic expansion (`http://www.sci-news.com/astronomy/science-universe-not-expanding-` `html`).

The argument based on the experimental findings of a team of astrophysicists led by Eric Lerner goes as follows. In non-expanding cosmology and also in the space around us (Earth, Solar system, Milky Way), as similar objects go further away, they look fainter and smaller. Their surface brightness remains constant. In Big Bang theory objects actually should appear fainter but bigger. Therefore the surface brightness- total luminosity per area - should decrease with distance. Besides this cosmic redshift would be dimming the light.

Therefore in expanding Universe the most distant galaxies should have hundreds of times dimmer surface brightness since the surface are is larger and total intensity of light emitted more or less the same. Unless of course, the total luminosity increases to compensate this: this would be of course total adhoc connection between dynamics of stars and cosmic expansion rate.

This is not what observations tell [E23]. Therefore one could conclude that Universe does not expand and Big Bang theory is wrong.

The conclusion is of course wrong. Big Bang theory certainly explains a log of things. I try to summarize what goes wrong.

(a) It is essential to make clear what time coordinate one is using. When analyzing motions in Solar System and Milky Way, one uses flat Minkowski coordinates of Special Relativity. In this framework one observes no expansion.

(b) In cosmology one uses Robertson-Walker coordinates (a, r, θ, ϕ). a and r are the relevant ones. In TGD inspired cosmology R-W coordinates relate to the spherical variant (t, r_M, θ, ϕ) of Minkowski coordinates by formulas

$$a^2 = t^2 - r_M^2, r_M = a \times r \ .$$

The line element of metric is

$$ds^2 = g_{aa}da^2 - a^2[dr^2/(1 + r^2) + r^2d\Omega^2] \ .$$

and at the limit of empty cosmology one has $g_{aa} = 1$.

In these coordinates the light-cone of empty Minkowski space looks like expanding albeit empty cosmology! a is just the light-cone proper time. The reason is that cosmic time coordinate labels the a=constant hyperboloids (hyperbolic spaces) rather than M^4 time=constant snapshots. This totally trivial observation is extremely important concerning the interpretation of cosmic expansion. Often however trivial observations are the most difficult ones to make.

Cosmic expansion would to high extend a coordinate effect but why should one then use R-W coordinates in cosmic scales? Why not Minkowski coordinates?

(a) In Zero Energy Ontology (ZEO) - something very specific to TGD - the use of these coordinates is natural since zero energy states are pairs of positive and negative energy states localized about boundaries of causal diamonds (CD), which are intersections of future and past directed light-cones having pieces of light-cone boundary as their boundaries. The geometry of CD suggests strongly the use of R-W coordinates associated with either boundary of CD. The question "Which boundary?" would lead to digression to TGD inspired theory of consciousness [K3].

(b) Thus the correct conclusion is that local objects such as stars and galaxies and even large objects do not participate in the expansion when one looks the situation in local Minkowski coordinates - which by the way are uniquely defined in TGD framework since space-time sheets are surfaces in $M^4 \times CP_2$. In General Relativity the identification of the local Minkowski coordinates could be highly non-trivial challenge.

In TGD framework local systems correspond to their own space-time sheets and Minkowski coordinates are natural for the description of the local physic since space-time sheet is by definition a space-time region allowing a representation as a graph of a map from M^4 to CP_2. The effects caused by the CD inside which the space-time surfaces in question belong to the local physics are negligible. Cosmic expansion is therefore not a mere coordinate effect but directly reflects the underlying ZEO.

(c) In General Relativity one cannot assume imbeddability of the generic solution of Einstein's equations to $M^4 \times CP_2$ and this argument does not work. The absence of local expansion have been known for a long time and Swiss Cheese cosmology has been proposed as a solution. Non-expanding local objects of constant size would be the holes of Swiss Cheese and the cheese around them would expand. In TGD framewor the holes of cheese would correspond to space-time sheets. All space-time sheets can be in principle non-expanding and they have suffered topological condensation to large space-time sheets.

One should also make clear GRT space-time is only an approximate concept in TGD framework.

(a) Einstein-Yang-Mills space-time is obtained from the many-sheeted space-time of TGD by lumping together the sheets and describing it as a region of Minkowski space endowed with an effective metric which is sum of flat Minkowski metric and deviations of the metrics of sheets from Minkowski metric. Same procedure is applied to gauge potentials.

(b) The motivation is that test particle topologically condenses at all space-time sheets present in given region of M^4andthe effects of the classical fields at these sheets superpose. Thus superposition of fields is replaced with superposition of their effects and linear superposition with set theoretic union of space-time sheets. TGD inspired cosmology *assumes* that the effective metric obtained in this manner allows imbedding as vacuum extremal of Kähler action. The justification of this assumption is that it solves several key problems of GRT based cosmology.

(c) The number of field patterns in TGD Universe is extremely small - given by preferred extremals - and the relationship of TGD to GRT and YM theories is like that of atomic physics to condensed matter physics. In the transition to GRT-Yang-Mills picture one gets rid of enormous topological complexity but the extreme simplicity at the level of fields is lost. Only four CP_2 coordinates appear in the role of fields in TGD framework and at GRT Yang-Mills limit they are replaced with a large number of classical fields.

This quantum view about cosmology will not be discussed further in this chapter most of which is written much before the emergence of zero energy ontology.

3 TGD Inspired Cosmology

Quantum criticality suggests strongly quantum critical fractal cosmology containing cosmologies inside cosmologies such that each sub-cosmology is critical before transition to hyperbolic phase. The general conceptual framework represented in the previous section give rather strong constraints on fractal cosmology. There are reasons to believe that the scenario to be represented, although by no means the final formulation, contains several essential features of what might be called TGD inspired cosmology.

Some remarks about interpretation are in order.

1. Equivalence Principle is assumed to hold true quite generally and the expression of gravitational four-momentum in terms of Einstein tensor is assumed to make sense in long length scales.

2. Robertson-Walker cosmology is taken as a statistical description replacing the many-sheeted space-time with single space-time sheet. The vanishing of density of inertial energy would be due to the smoothing out of the topological condensate of CP_2 type vacuum extremals and cosmic strings (carrying also these condensates) and giving to the inertial four-momentum a contribution expressible in terms of Einstein tensor in statistical description.

3. TGD inspired cosmology has the structure of Russian doll. Dark matters at various pages of the Big Book defined by the hierarchy of Planck constants defines one hierarchy of cosmologies. There is also a hierarchy of causal diamonds (CDs) defined as the intersection of future and past directed light-cones. Zero energy state associated with CDs could be interpreted as not so big bang followed by not so big crunch as the time scale of CD becomes long enough. In short time scales the interpretation would be in terms of particle reaction. Subcosmologies can be generated from vacuum spontaneously so that one has a p-adic hierarchy of cosmologies within cosmologies. If the size of CD is assumed to come as power of 2 as the geometry of CD suggests, p-adic length scale hypothesis follows.

4. The understanding of the non-conservation of gravitational energy associated with a comoving volume has been a long standing issue in TGD. The conservation of four-momentum is an un-necessarily strong assumption in statistical description since in zero energy ontology four-momentum is conserved only inside causal diamond (CD). The rate for change of the gravitational energy in a given co-moving volume could be interpreted to reflect this statistical non-conservation. The original interpretation for the non-conservation of gravitational energy was in terms of topological evaporation and condensation of space-time sheets and cosmic strings carrying topological condensate of particles, and more generally, in terms of the transfer of energy between different space-time sheets. One cannot exclude the presence of also these mechanisms.

In the following discussion only a sub-cosmology associated with a given CD is discussed and the considerations assume that the time scale of observations is short as compared with the time scale of CD so that positive energy ontology is a good approximation.

3.1 Primordial Cosmology

TGD inspired cosmology has primordial phase in which only vapor phase containing only cosmic strings containing topological condensate of fermions is present and lasting to $a \sim R$. During this period it is not possible to speak about space-time in the sense of General Relativity. The energy density and "pressure" of cosmic strings in vapor phase (densities in $M^4_+ \times CP_2$ are assumed to be

$$\begin{aligned} \rho_V &= \frac{3}{8\pi G a^2} \ , \\ p &= -\frac{\rho}{3} \ . \end{aligned} \tag{3.1}$$

This assumption would mean that gravitational energy and various gravitational counterparts of the classical charges associated with the isometries of H are conserved during vapor phase period. This assumption guarantees consistency with the critical cosmology and by the requirement that the mass per co-moving volume vanishes at the limit $a \rightarrow 0$ so that the Universe is apparently created from nothing. The interactions between cosmic strings are pure contact interactions and extremely weak and it seems natural to assume that the temperature of the vapor phase is zero.

3.2 Critical Phases

The mere finiteness of Kähler action does not allow vapor phase to endure indefinitely since the Kähler magnetic action of the free cosmic string is positive and infinite at the limit of infinite duration. The topological condensate of fermions necessarily present reduces this action. Second manner to reduce it is creation of space-time sheets at which cosmic strings condense on them and generate Kähler electric fields compensating the positive Kähler magnetic action. Individual cosmic string can however stay as free cosmic string for arbitrarily long time since the finite magnetic Kähler action can be compensated by the correspondingly larger electric Kähler action. In principle cosmic strings can be created as pairs of positive and negative inertial energy cosmic strings from vacuum in vapor phase.

In accordance with this primordial phase is followed by the generation of critical cosmologies as "Silent Whispers" amplifying to "Big Bangs" basically by emission of ordinary matter by Hawking radiation, and possibly by gravitational heating made possible by the emission of negative energy virtual gravitons as "acceleration radiation" as matter gains strong inertial energies in gravitational fields. p-Adic length scale hypothesis allows to deduce estimates for the typical time for the creation of a critical cosmology, the duration of the critical phase, the temperature achieved during the critical phase and the duration of the hyperbolic expanding phase possibly following it and transforming to a phase in which cosmic expansion ceases and space-time surface behaves like a particle.

What is of extreme importance is that the deceleration parameter q associated with critical and over-critical cosmologies is negative. It is given by

$$q = -K_0 \frac{K_0 u^2}{1-u^2-K_0} < 0 \ , \ \ u = a/a_1 \ , \tag{3.2}$$

where K_0 and a_1 are the parameters appearing in $g_{aa} = 1 - K$, $K = K_0/(1-u^2)$.

The rate of change for Hubble constant is

$$\frac{dH/ds}{H^2} = -(1+q) \ , \tag{3.3}$$

so that one must have $q < -1$ in order to have acceleration. This holds true for $a > \sqrt{(1-K_0)/(1+K_0)}a_1$. This allows to understand the recently discovered acceleration of late cosmology as assignable to a quantum critical phase transition increasing cosmological constant and thus leading to an increase of the size of the large void.

This model is discussed in detail in [K7] and shown to explain the observed jerk about 13 billion years changing deceleration to acceleration. The recently observed cold spot in cosmic microwave background [E1] can be understood as a presence of large void with size of about 10^8 ly already about 10^{10} years ago. This conforms with the hypothesis that large voids increase their size in phase transition like manner rather than participating in cosmic expansion in continuous manner.

3.3 Radiation Dominated Phases

p-Adic length scale hypothesis suggests that the typical moments of birth $a_0(k)$ and durations $a_1(k)$ for the critical cosmologies satisfy $a_0(k) \sim L(k)$ and $a_1(k) \sim L(k)$, where k prime or power of prime, $L(k) = l \times 2^{k/2}$, $l = R \simeq 10^{3.5}$ Planck lengths, and n is a numerical factor. p-Adic length scale hypothesis suggest that the temperature just after the transition to the effectively radiation dominated phase is

$$\begin{aligned} T(k) &= \frac{n}{L(k)} \ , \qquad \text{for } k > k_{cr} \ , \\ T(k) &= T_H \sim \frac{1}{R} \ , \quad \text{for } k \leq k_{cr} \ . \end{aligned} \tag{3.4}$$

Here n is rather large numerical factor. Since $a_F \sim 2.7 \times 10^{-10}$ seconds which corresponds to length scale $L \simeq .08$ meters roughly to p-adic length scale $L(197) \simeq .08$ meters (which by the way corresponds to the largest p-adic length scale associated with brain, a cosmic joke?!), should correspond to the establishment of Hagedorn temperature, one has the conditions

$$\begin{aligned} k_{cr} &= 197 \ , \\ n &\simeq 2^{197/2} \sim 10^{30} \sim \frac{m_{CP_2}^2}{m_p^2} \ . \end{aligned}$$

Thus n is in of same order of magnitude as the ratio of the CP_2 mass squared ($m_{CP_2} \simeq 10^{-3.5}$ Planck masses) to proton mass squared.

Dimensional considerations suggest also that the energy density in the beginning of the radiation dominated phase (in case that it is achieved) is

$$\rho = nT^4(k) \ , \tag{3.5}$$

where n a numerical factor of order one. n does not count for the number of light particle species since the thermal energy of strings could give rise to the effective radiation dominance. Furthermore, if ordinary matter is created by Hawking radiation and by radiation generated by the ends of split strings, the large mass and Hagedorn temperature as a limiting temperature could make impossible the generation of particle genera higher the three lowest ones (see [K5] for the argument why $g > 2$ particle families (g denotes the genus of partonic 2-surface) have ultra heavy masses). Thus it seems that the infinite number of fermion families cannot lead to an infinite density of thermal energy and why their presence leaves no trace in present day cosmology.

When the time parameter a_1 of the critical cosmology grows too large, it cannot anymore generate radiation dominated phase since the temperature remains too low. Previous considerations suggest that the maximum value of a_1 is roughly $a_1(max) = a_F \sim 3 \times 10^{-10}$. After this critical sub-cosmologies would transform directly to the stationary cosmologies.

Radiation dominated phase transforms to matter dominated phase and possibly decomposes to disjoint 3-surfaces with size of order horizon size at the same time. p-Adic length scale hypothesis suggests that the duration of the radiation dominated phase with respect to the proper time of the space-time sheet is or order

$$s_2 \equiv \int_{a_1}^{a_1+a_2} \sqrt{g_{aa}}da \sim L(k) \ . \tag{3.6}$$

In case of "our" radiation dominated cosmology this gives correct estimate for the moment of time when transition to matter dominated phase occurs since one has $L(k) \sim a_F$ in this case.

That the decomposition to disjoint 3-surfaces occurs after the transition to matter dominated phase is suggested by simple arguments. First of all, the decomposition into regions has obviously interpretation as a formation of visible structures around hidden structures formed by pairs of cosmic strings thickened to magnetic flux tubes. Secondly, of decomposition occurs, the photons coming from distant objects "drop" to the space-time sheets representing later critical cosmologies. This explains why the optical properties of the Universe seem to be those of a critical cosmology.

3.4 Matter Dominated Phases

The transition to the matter dominated phase followed by the decoupling of the radiation and matter makes possible the formation of structures. This is expected to involve compression of matter to dense regions and to lead to at least a temporary decomposition of the matter dominated cosmology to disjoint 3-surfaces condensed on larger space-time surfaces. The reason is that Jeans length becomes smaller than the size of the horizon. A galaxy model based on the assumption that the region around the two curved ends of a split cosmic string serve as a seed for galaxy formation has been considered in [K7]. In particular, it was found that Jeans criterion leads to a lower bound for the string tension of the galactic strings of same order of magnitude as the string tension of the cosmic strings.

If one assumes that matter dominated regions continue cosmological expansion so that the radius of region equals to the horizon size $R = a^{1/2}$, the fraction of the volume occupied by matter dominated regions grows as $\epsilon(a) = (a/a_R)\epsilon(a_R)$. In recent cosmology the regions have joined together for $\epsilon(a_R) > 10^{-3}$ which would suggest that ultimately asymptotic string dominated cosmology results. One could however argue that matter dominated cosmology does not expand. Taking into account the horizon size of about 5×10^5 light years at the time of the transition to matter dominance, this would mean that galaxies do not participate in cosmic expansion but move as particles on background cosmology.

TGD allows an entire sequence of matter dominated cosmologies associated with the radiation dominated cosmologies labeled by p-adic primes allowed by p-adic length scale hypothesis. Forgetting the delicacies related to nucleo-synthesis, the matter densities associated with these matter dominated cosmologies are scaled down like $(a_1(k)/a_F)^3$ where $a_1(k)\sin L(k)$ is the moment at which the corresponding critical cosmology was created. Thus the latest matter dominated cosmology gives the dominating contribution to the matter density.

Sooner or later matter dominated cosmology becomes string dominated. A good guess is that the transition to string dominance occurs if cosmic expansion of the space-time sheet indeed continues. To see what is involved consider the bounds on the total length of string per large void with size of order $a_* \sim 10^8$ light years. This length can be parameterized as $L = nL(void)$. The requirement that the mass density of the strings is below the critical density gives, when applied to the large void with size of $a_* \simeq 10^8$ light years at recent time a, gives

$$\frac{3}{4\pi}\frac{nT}{a_*^2} < \rho_s = \frac{3}{8\pi G a^2} \quad . \tag{3.7}$$

Here one has $T \simeq .22 \times 10^{-6}\frac{1}{G}$. This gives roughly

$$n < 2 \times 10^6 \times (\frac{a_*}{a})^2 \quad . \tag{3.8}$$

The second constraint is obtained from the requirement that the ratio of the string mass per void to the mass of the ordinary matter per void is not too large at present time. Using the expression

$$\rho_m \simeq \frac{3}{32\pi G}\frac{a_*}{a^3} \quad ,$$

with $a_* \sim 10^8$ years (time of recombination) and the expression for the string mass per void one has

$$\frac{\rho_s(a)}{\rho_m a(a)} = n \times 1.8 \times 10^{-6} (\frac{a}{a_*})^3 \quad . \tag{3.9}$$

for the ratio of the densities. For $a = 10^{10+1/2}$ ly the two conditions give

$$\begin{aligned} n &< 20 \ , \\ \frac{\rho_s(a)}{\rho_m} &\simeq n \times 18 \times \sqrt{10} \quad . \end{aligned} \tag{3.10}$$

These equations suggest that n cannot be much larger than one and suggest the simple picture in which the Kähler charges associated with the "big" string in the interior of the large void and with the galactic strings on the boundaries of the void cancel each other. The minimal value of n is clearly $n = 4$ corresponding to a straight string in the interior of the void. It must be however emphasized that these estimates are rough.

The rate $dlog(E_{gr})/dlog(a)$ for the change of gravitational energy in co-moving volume at present moment in the matter dominated cosmology is determined by

$$\frac{(d\rho_c/da)}{\rho_c} = -\frac{1}{2a} \sim 10^{-11} \frac{1}{year} \quad . \tag{3.11}$$

The rate is of the same order of magnitude as the rate of energy production in Sun [E27] so that the rates dE_{I+}/da and dE_{I-}/da for the change of positive and negative contributions to the inertial energy would be of same order of magnitude and sum up to dE_{gr}/da.

3.5 Stationary Cosmology

The original term was asymptotic cosmology but stationary cosmology is a better choice if one accepts the notion of quantal cosmology. In this kind of situation expects that stationary cosmologies correspond to stationary quantum states during which topologically condensed space-time sheets do not participate the cosmic expansion but co-move as point like particles.

During stationary cosmology one has $dE_{gr}/da = 0$. In zero energy ontology the interpretation is that the apparent non-conservation of gravitational (=inertial) energy due to the change of time scale characterizing typical causal diamond (CD) is not present anymore. The following argument suggests that asymptotic cosmology is equivalent with the assumption that the cosmic expansion of the space-time sheets almost halts. The expression for the horizon radius for the cosmology decomposing into critical, radiation and matter dominated and asymptotic phases. The expression for the radius reads as

$$R = \int_0^a \sqrt{g_{aa}} \frac{da}{a} = R_0 + R_{as} \quad ,$$

where R_0 corresponds from the cosmology before the transition to the asymptotic cosmology and R_{as} gives the contribution after that. Formally this expression is infinite since the contribution to R_{as} from the critical period is infinite. Since one has $g_{aa} \rightarrow 1$ asymptotically R_{as} is in good approximation equal to $R_{as} = log(a/a_{as})$, where a_{as} denotes the time for the transition to asymptotic cosmology. This means that the growth of the horizon radius becomes logarithmically slow: $dR(a)/da = 1/a$. A possible interpretation is that the sizes of various structures during asymptotic cosmology are almost frozen. One can however consider the possibility that the disjoint structures formed during the period of matter dominated phase expand and fuse together so that the there is basically single structure of infinite size formed by the join along boundaries condensate of various matter carrying regions.

From the known estimates [E32] for the total length of galactic string per void one obtains estimate for the needed string tension of the galactic strings. The resulting string tension is indeed of the order of GUT string tension $T \sim 10^{-6}/G$. It will be found later that Jeans criterion gives same lower bound for the string tension of the galactic strings. The resulting contribution to the mass density is smaller than the critical mass density so that no inconsistencies result.

The simplest mechanism generating galactic strings is the splitting of long strings to pieces resulting from the collisions of the strings during very early string dominated cosmology. This mechanism implies that galaxies should form linear structures: this seems indeed to be the case [E32].

The recent mass density of the strings is considerably larger than that associated with the visible matter. This implies string dominance sooner or later. There are two possible alternatives for the string dominated cosmology.

1. Cosmology with co-moving strings.
2. Stationary cosmology, which seems a natural candidate for the asymptotic cosmology.

Consider first the co-moving string dominated cosmology. The mass density for the string dominated Robertson-Walker cosmology (necessarily smaller than critical density now) is given by the expression

$$\begin{aligned} \rho &= \frac{3}{8\pi G a^2}(\frac{1}{K}-1) \ , \\ H^2 &= \frac{1}{Ka^2} \ , \end{aligned} \tag{3.12}$$

and is a considerable fraction of the critical mass density unless the parameter K happens to be very close to 1. Sub-criticality gives the condition

$$c_{\#} = \sqrt{K} > \frac{1}{\sqrt{2}} \ .$$

The requirement that the gravitational force dominates over the Kähler force implies that the value of $g_{aa} = K$ differs considerably from unity. The recent value of the quantity Ka^2 can be evaluated from the known value of the Hubble constant. By the previous argument, the ratio of the string mass density to the matter mass density for the recent time $a \sim 10^{10+1/2}$ years is about $\rho_s/\rho_m \sim 50$. This gives the estimates for the light velocity in the condensate and the ratio of the density to the critical density

$$\begin{aligned} c_{\#} &= \sqrt{K} \simeq .93 \ , \\ \Omega \equiv \frac{\rho}{\rho_{cr}} &\simeq .16 \ . \end{aligned} \tag{3.13}$$

One also obtains an estimate for the time a_1, when the transition to string dominated phase has occurred

$$\begin{aligned} \rho_{m0} &= \rho_m(\frac{a}{a_1})^3 = \rho_s = \rho_{s0}(\frac{a}{a_1})^2 \ , \\ a_1 &= \frac{\rho_m}{\rho_s} a \sim 6\times 10^8 \ \text{ly} \ . \end{aligned} \tag{3.14}$$

The fraction of the total mass density about the critical mass density is about 4 per cent an perhaps two small.

Consider next the stationary cosmology. The relevant component of the metric and mass density are given by the expressions

$$\begin{aligned} g_{aa} &= \frac{(1-2x)}{(1-x)} \ , \\ \rho &= \frac{3}{8\pi G a^2}\frac{x}{(1-2x)} \ , \\ x &= (\frac{a_1}{a})^{2/3} \ . \end{aligned} \tag{3.15}$$

Asymptotically the mass density for this cosmology behaves as $\rho \simeq 1/a^{2(1+v^2)}$, $v^2 = 1/3$ and "pressure" ($p \simeq -1/9\rho$) is negative indicating that strings indeed dominate the mass density. The results from the numerical simulation of the GUT cosmic strings suggest the interpretation of v^2 as mean square velocity for a long string [E10]: the relative velocities of the big strings seem rather large.

The transition to the stationary cosmology must take place at some finite time since the energy density

$$\rho = \frac{3}{8\pi G a^2}\frac{(\frac{a_1}{a})^{2/3}}{(1-2(\frac{a_1}{a})^{2/3})} \ , \tag{3.16}$$

is negative, when the condition $a < a_1(1/2)^{-3/2}$ holds true. An estimate for the parameter a_1 is obtained by requiring that the ratio of the mass density to the recent density of the ordinary matter is of order $r \sim 200$ at time $a \sim 10^{10.5}$ ly (this requires $n = 4$, which corresponds to the lower bound for the length of cosmic string per void): $\frac{\rho}{\rho_m}(a) = r$. This gives for the parameter x, the time parameter a_1, the velocity of light in the condensate and for the fraction of the mass density about the critical mass density the following estimates:

$$\begin{aligned} x &= \frac{\frac{r}{4}\frac{a_*}{a}}{1+\frac{r}{2}\frac{a_*}{a}} \simeq .16 \ , \\ a_1 &\simeq 2\times 10^9 \ \text{ly} \ , \\ c_\# &\simeq .93 \ , \\ \Omega &\simeq .16 \ . \end{aligned} \tag{3.17}$$

Apart from the value of the transition time, the results are essentially the same as for the string dominated cosmology. By increasing the amount of a string per void one could reduce the value of the light velocity in the condensate. The experimental lower bound on Ω is $\Omega > .016$ and the favored value is $\Omega \sim .3$. The latter value would require $n \simeq 6.8$ instead of the lower bound $n = 4$ and give $c_\# \simeq .87$

If the proposed physical interpretation for dE_{gr}/da in terms of the energy production inside the stars is correct, then stationary cosmology should be a good idealization for the cosmology provided that the rate of the energy production of stars is negligibly small as compared with the total energy density. This is expected to case, when the energy density of the string like objects begins to dominate over the ordinary matter.

String dominated and stationary cosmologies have certain common characteristic features:

1. Horizons are absent. This implies that the formation of the structures of arbitrarily large size should be possible at this stage and in certain sense the formation of these structures can be regarded as a manifestation of the structures already formed during the very early string dominated cosmology.

2. The so called acceleration parameter q_0 vanishes asymptotically for the stationary cosmology and identically for string dominated cosmology: The deceleration parameter

$$q = \frac{1}{3}\frac{x}{(1-2x)(1-x)} \ . \tag{3.18}$$

The value of q is positive and conforms with the identification of stationary cosmology as counterpart of stationary state in which topologically condensed space-time sheets co-move but do not expand.

For the matter dominated cosmology the value of this parameter is $q_0 = 1/2$ and positive ($a \simeq t^{2/3}$). The earlier attempts made to evaluate the value of this parameter from the observations are consistent with the value $q_0 = 0$ as well as with the value $q_0 = 1/2$ [E27]. Quite recent determinations of the parameter [E17] are consistent with $q_0 \leq 0$ but exclude large negative values of q_0 typical for the inflationary scenarios with a large value of the cosmological constant.

4 Inflationary Cosmology Or Quantum Critical Cosmology?

The measurements [E8] allow to deduce information about the curvature properties of the space-time in cosmological scales. These experimental findings force the conclusion that cosmological time= constant sections are essentially flat after the decoupling of the em radiation from matter which occurred roughly one half million years after the Big Bang. The findings allowed to build a much more detailed model for the many-sheeted cosmology leading also to a considerable increase in the understanding of the general principles of TGD inspired cosmology. In the following the observational facts are discussed first and then TGD based explanation relying on the many-sheeted cosmology is briefly discussed. One ends up to a cosmological realization of quantum criticality in terms of a fractal cosmology having Russian doll like structure. The cosmologies within cosmologies are critical cosmologies before transition to hyperbolicity followed by an eventual decay to disjoint non-expanding 3-surfaces.

Critical cosmologies can be regarded as "Silent Whispers" amplifying to Big Bangs and are generated from vacuum by the gradual condensation of cosmic strings to initially empty and flat space-time sheets. The transition to hyperbolicity involves topological condensation of the remnants of the earlier sub-cosmologies. Hyperbolic period is followed by a decay to disjoint non-expanding 3-surfaces, remnants of the sub-cosmology. There is thus a strong analogy with biological evolution involving growth, metabolism and death. Sub-cosmologies are characterized by three parameters: moment of birth and durations of the critical period and hyperbolic periods. p-Adic length scale hypothesis makes model quantitative by providing estimates for the moments of cosmic time when the phase transitions generating new critical sub-cosmologies occur and fixes the number of the phase transitions already occurred. What is especially remarkable, that the time for the generation of CMB is predicted correctly from p-adic fractality and from the absence of the second acoustic peak in the spectrum of CMB fluctuations.

The recent measurements [E8] allow to deduce information about the curvature properties of the space-time in cosmological scales. The conclusion is that cosmological time= constant sections are essentially flat after the decoupling of the em radiation from matter which occurred roughly one half million years after the Big Bang. This forces to consider a more detailed model for the many-sheeted cosmology provided by TGD. In the following the observational facts are discussed first and then TGD based explanation relying on the many-sheeted cosmology is discussed. One ends up to a cosmological realization of quantum criticality in terms of a fractal cosmology having Russian doll like structure. The cosmologies within cosmologies are critical cosmologies before transition to hyperbolicity followed by an eventual decay to disjoint non-expanding 3-surfaces.

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It must be emphasized that in TGD framework critical cosmology reflects quantum criticality and the presence of two kinds of two-dimensional conformal symmetries acting at the level of imbedding space and space-time [K23]. Thus the correlation function for the fluctuations of the mass density at the surface of a sphere of fixed radius is dictated by conformal invariance and by quantal effects the naive scaling dimension predicted by the scaling invariance can be modified to an anomalous dimension. The implications of replacing scaling invariance with conformal invariance for the correlation function of density fluctuations is discussed at the general level in [E7].

4.1 Comparison With Inflationary Cosmology

TGD differs from GRT in several respects. Many-sheeted space-time concept forces fractal cosmology containing cosmologies within cosmologies. A p-adic hierarchy of long ranged electro-weak and color physics assignable to dark matter at various space-time sheets is predicted if one interprets the unavoidable long ranged classical gauge fields as space-time correlates of corresponding quantum fields. Confinement (weak) length scales associated with these physics correspond to p-adic length scales characterizing the sizes of the space-time sheets of corresponding hadrons (weak bosons). Topological condensation involves a formation of # contacts identifiable as parton-antiparton pairs defining a particular instance of dark matter. Infinite variety of dark matters, or more precisely partially dark matters with respect to each other, is predicted.

Z^0 force competes with gravitational force and it will be found that the role of this force could be crucial in understanding the formation of the observed large void regions (with recent size of order 10^8 light years) containing ordinary matter predominantly on their boundaries. Einstein's equations provide only special solutions of the field equations for the length scale dependent space-time of TGD. For instance, in case of strongly Kähler charged cosmic strings it seems better to regard the strings as sources of the Kähler electric field rather than gravitational field. Vapor phase containing at least cosmic strings is the crucial element of TGD inspired cosmology.

The proposed scenario for cosmology deserves a comparison with the inflationary scenarios [E6, E5].

1. In inflationary cosmologies exponentially expanding phase corresponds to a symmetry non-broken phase and de-Sitter cosmology follows from the vacuum energy density for the Higgs field. The vacuum energy of the Higgs field creates "negative pressure" giving rise to the exponential expansion. The string tension of the topologically condensed cosmic strings creates the "negative pressure" in TGD context.

   In TGD framework the period with Minkowskian signature of induced metric is analogous to inflationary period. This can be seen by solving proper time t in terms of M^4_+ proper time a from the equation

   $$\frac{dt}{da} = \sqrt{g_{aa}} = \sqrt{1 - \frac{R^2k^2}{4}\frac{1}{1-k^2a^2}} \ . \tag{4.1}$$

   From this expression one sees that the dt/da evolves from very small and finite value to zero at $ka = kR/2$ so that da/dt is infinite at the end of Minkowskian period. The value of da/dt approach infinity for radiation dominated cosmology with $t \propto a^2$ so that a good guess is that space-time sheets with radiation dominated cosmology begin to be generated.

2. In the inflationary scenarios the exponential expansion destroys inhomogenuities and implies the isotropy of 3 K radiation and the decay of the Higgs field to radiation creates entropy. In TGD string dominance implies the absence of horizons. There are no horizons associated with the vapor phase neither since it obeys light cone cosmology. Also critical, string dominated and asymptotic cosmologies are horizon free.

3. In inflationary scenarios the transition to the radiation dominated phase corresponds to the transition from the symmetric phase to a symmetry broken phase. In TGD something analogous happens. Cosmic strings are free at primordial stage but unstable against decay to elementary particles because their action has wrong sign. Some of these strings achieve stability by topologically condensing and generating large Kähler electric charge to cancel their Kähler magnetic action. Light particles of matter in turn suffer a gradual condensation around Kähler electric strings. The Kähler charge of the string induces automatically a slight matter-antimatter asymmetry in the exterior space-time. Or vice versa: the surrounding vacuum extremal must suffer a slight deformation to non-vacuum extremal and this requires Kähler electric field and simplest field of this kind is radial one forcing cosmic string to generate small Kähler charge. At the limit $a \to 0$ the contribution of the condensate to the energy of a given co-moving volume vanishes and in this sense condensate can be regarded as a seed of the symmetry broken phase.

4. In inflationary scenarios the critical mass density is reached from above and final state corresponds to a cosmology with a critical mass density. In TGD scenario in its simplest form, the mass density is exactly critical before the transition to the "radiation dominated phase" and overcritical mass density resides in the vapor phase. In a well defined sense vapor phase makes possible sub-critical cosmology. The mysterious vacuum energy density of the inflationary cosmologies could corresponds in TGD framework to the dark matter density at cosmic strings part of which could be in vapor phase.

Also critical cosmology involves a rapid expansion and one can imagine what this means in TGD framework if one takes p-adic length scale hypothesis and the hierarchy of Planck constants seriously. This point will be discussed in separate section.

4.2 Balloon Measurements Of The Cosmic Microwave Background Favor Flat Cosmos

Inflationary scenario has been one of the dominating candidates for cosmology. The basic prediction of the inflationary cosmology is criticality of the mass density which means that cosmic time=constant sections are flat. Observations about the density of known forms of matter are not consistent with this and the only possible manner to get critical mass density is to assume that there exist some hitherto unknown form of vacuum energy density contributing roughly 70 percent to the energy density of the universe. This vacuum energy density is believed to cause the observed acceleration of the cosmic expansion.

The basic geometrical prediction of the inflationary scenario is that cosmic time=constant sections are flat Euclidian 3-spaces. This prediction has been now tested experimentally and it seems that the predictions are consistent with the observations. The test is based on the study of non-uniformities of the cosmic microwave background (CMB). CMB was created about half million years after the moment of Big Bang when opaque plasma of electrons and ions coalesced into transparent gas of neutral hydrogen and helium. Thermal photons decoupled from matter to form cosmic microwave background and have been propagating practically freely after that. The fluctuations of the temperature of the cosmic microwave background reflect the density fluctuations of the universe at the time when this transition occurred. The prediction is that the relative fluctuations of temperature are proportional to the relative fluctuations of mass density and are few parts to 10^5.

Happily, it is possible to estimate the size spectrum for the regions of unusually high and low density theoretically and compare the predictions with the experimentally determined distribution of hot and cold spots in CMB. Since the light from hot and cold spots propagates through the intervening curved space, its intrinsic geometry reflects itself in the properties of the observed spectrum of CMB fluctuations. Hence it becomes possible to experimentally determine whether the 3-space (cosmic time=constant section) is negatively curved (expansion forever), positively curved and closed (big crunch) or flat.

The acoustic properties of the plasma help in the task of determining the spectrum of CBM fluctuations. The competition between gravity and radiation pressure during radiation dominated period produced regions of slow, attenuated oscillatory contraction and expansion. The maximum size of over-dense region that could have shrunk coherently during the half million years before the plasma became transparent was limited by the velocity of sound which is $c/\sqrt{3}$ in radiation dominated plasma. This gives $R = 5/\sqrt{3} \times 10^5$ light years which is about 300 thousand light years for the maximal size of the hot spot. The observed position and size of the first acoustic peak corresponding to the largest hot spots and its observed position depends on the presence or absence of the distorting cosmic curvature. If the intervening 3-space is positively (negatively) curved the parallel rays coming from hot spot diverge and hot spots look larger (smaller) than they actually are: also distances between hot spots look larger (smaller).

To abstract cosmological details from the observations one calculates the power spectrum of the thermal fluctuations by fitting the CMB temperature map to a spherical harmonic series. The absolute square of the fitted amplitude for l: th order spherical-harmonic component is essentially the mean-square point-to-point temperature fluctuation of the CMB on angular scale about π/l radians. The observed fluctuation power spectrum as function of l has maximum at $l = 200$. This is consistent with flat intervening 3-space and inflationary scenario. The next maximum of power spectrum as function of l corresponds to the second acoustic peak (recall that acoustic oscillations are in question) with smaller size of hot spot and should be observed at $l = 500$ according to inflationary scenario. In fact this peak has not been observed. This might be due to the small statistics or due to the fact that the scale free prediction of the inflationary scenario for the spectrum of fluctuations is quite not correct but that fluctuations have cutoff at some length scale larger than the size of the size of the hot spot associated with the second acoustic peak.

In standard cosmology the result means that 3-space has remained flat for most of the time after the moment when CMB was generated. Of course, the cosmology can have changed hyperbolic after that since the small mass density of the recent day universe implies that the effects of the curvature on the optical properties of the universe are small. Inflationary scenario predicts this if one repeats the biggest blunder of Einstein's life by adding to Einstein's equations cosmological constant, which means that vacuum energy density of an unknown origin contributes about 70 per cent to the mass density of the universe. Besides this one must assume that primordial baryon density is about 50 per cent higher than standard expectation. Thus inflationary model survives the test but not gracefully.

4.3 Quantum Critical Fractal Cosmology As TGD Counterpart Of The Inflationary Cosmology

In TGD framework Einstein's equations are structural equations relating the energy momentum tensor of topologically condensed matter to the geometry of the space-time surface rather than fundamental equations derivable from a variational principle. Furthermore, the solutions of Einstein's equations are only a special case of the equations characterizing the macroscopic limit of the theory. The simplest assumption is however that Einstein's equations hold true for each sheet of the many-sheeted space-time and is made in TGD inspired cosmology.

4.3.1 Does quantum criticality of TGD imply criticality and fractality of TGD based cosmology?

Quantum criticality of the TGD Universe supports the view that many-sheeted cosmology is in some sense critical. Criticality in turn suggests p-adic fractality. Phase transitions, in particular the topological phase transitions giving rise to new space-time sheets, are (quantum) critical phenomena involving no scales. If the curvature of the 3-space does not vanish, it defines scale: hence the flatness of the cosmic time=constant section of the cosmology implied by the criticality is consistent with the scale invariance of the critical phenomena. This motivates the assumption that the new space-time sheets created in topological phase transitions are in good approximation modellable as critical Robertson-Walker cosmologies for some period of time at least.

Neither inflationary cosmologies nor overcritical cosmologies allow global imbeddings. TGD however allows the imbedding of a one-parameter family of critical and overcritical cosmologies. Imbedding is possible for some critical duration of time. The parameter labeling these cosmologies is a scale factor characterizing the duration of the critical period. The infinite size of the horizon for the imbeddable critical cosmologies is in accordance with the presence of arbitrarily long range fluctuations at criticality and guarantees the average isotropy of the cosmology. These cosmologies have the same optical properties as inflationary cosmologies.

The critical cosmologies can be used as a building blocks of a fractal cosmology containing cosmologies containing... cosmologies. p-Adic length scale hypothesis allows a quantitative formulation of the fractality. Fractal cosmology provides explanation for the balloon experiments and also for the paradoxical result that the observed density of the matter is much lower than the critical density associated with the largest space-time sheet of the fractal cosmology. Also the observation that some astrophysical objects seem to be older than the Universe, finds a nice explanation.

4.3.2 Cosmic strings and vapor phase

En essential element of TGD inspired cosmology is the presence of vapor phase consisting dominantly of cosmic strings. For the values of light cone proper time a smaller than CP_2 time R, space-time does not exist in sense as it is defined in General Relativity. Instead, very early Universe consists of a primordial soup of cosmic strings. General arguments lead to the hypothesis that the density of the cosmic strings in vapor phase in in this period is

$$\rho_V = \frac{3}{8\pi G a^2} \ . \tag{4.2}$$

The expression of the density is formally same as the critical density of flat critical cosmology (note that future light cone is hyperbolic vacuum cosmology). The topological condensation of free cosmic strings could be forced by the absolute minimization of Kähler action (free cosmic strings have infinite positive Kähler magnetic action) to critical space-time sheets leads to fractal hierarchy of critical cosmologies and reduces the density of vapor phase. Obviously the energy density in vapor phase is very much analogous to the vacuum energy density needed in inflationary cosmologies. Note however that absolute minimization is only one of the many interpretation for what preferred extremaly property could mean.

4.3.3 What happens when criticality becomes impossible?

Given critical sub-cosmology is created at the moment $a = a_0$ of the light cone proper time. The imbeddability of the critical cosmology fails for $a = a_1$. The question is what happens for the space-time sheet before this occurs. A natural assumption is that when the value of the cosmic time for which imbeddability fails is approached, cosmology is transformed to hyperbolic cosmology. One can imagine several scenarios but the following one involving two transitions is the most plausible one. The first step is the transition of the critical cosmology to a hyperbolic cosmology which is either matter or radiation dominated or to a stationary cosmology for which gravitational energy density is conserved. The next step is possible decomposition of $a = constant$ 3-surface of hyperbolic cosmology to disjoint non-expanding 3-surfaces topologically condensing on critical cosmology created later. This process in turn could induce the transition of the critical cosmology to hyperbolicity: when critical sub-cosmology eats the remnants of earlier sub-cosmology it could become hyperbolic itself. Of course, this is not the only mechanism. This scenario resembles to high degree the lifecycle of a biological organism involving gradual growth, metabolism and death.

1. Transition to matter or radiation dominated phase

The critical cosmology is transformed to a hyperbolic cosmology with sub-critical mass density. This option is very general and means that criticality is gradually shifted to increasingly longer length scales when it breaks down in short length scales. The continuity condition in the transformation to hyperbolic cosmology with $\theta = \pi/2$ and $\phi = \phi(a)$ for g_{aa} reads as

$$\begin{aligned} \frac{1}{g^H_{aa}} - 1 &= \frac{1}{1-K} \equiv \epsilon \ , \\ K &\equiv \frac{R^2}{4a_1^2}\frac{1}{(1-(\frac{a}{a_1})^2)} \ . \end{aligned} \tag{4.3}$$

The light cone projection of the sub-cosmology is sub-ligtcone of M^4_+. a denotes light cone proper time for this sub-light cone: its value is obviously smaller than the value of M^4_+ proper time. Upper index "H" refers to to the metric of the hyperbolic cosmology. The value of the parameter ϵ must deviate considerably from unity and and since R/a_1 is extremely small number, the transformation to hyperbolic cosmology must happen very near to $a = a_1$: for all practical purposes this fixes the moment of transition to be $a = a_1$. Critical cosmology is also flat in excellent approximation up to $a = a_1$. The mass density of the hyperbolic cosmology behaves during the matter (radiation) dominated phase as

$$\rho = \frac{3}{8\pi G}\epsilon\frac{a_1^{1+n}}{a^{3+n}} \ . \tag{4.4}$$

Here $n = 0$ corresponds to matter dominance and $n = 1$ to radiation dominance.

2. Decomposition of $a = constant$ surface to disjoint non-expanding components p-Adic length scale hypothesis suggests that hyperbolic sub-cosmology ceases to participate in the cosmic expansion sooner or later and that $a = constant$ 3-surface decomposes to disjoint particle like non-expanding objects topologically condensing at and comoving on the sub-cosmologies generated later. A possible mechanism causing the decomposition of a hyperbolic sub-cosmology into disjoint space-time sheets is the intersection of the sub-light cones defined by the sub-cosmologies initiated at same $a = constant$ hyperboloid. The transition to non-expanding phase has certainly occurred for stellar objects.

The disjoint 3-surfaces generated in this process are topologically condensed at (or are "metabolized" by) younger critical cosmologies and the simplest assumption is that this condensation process changes the newer cosmology to matter dominated hyperbolic cosmology. This assumption is consistent with the fact that the mass density of the critical cosmologies is very small before the transformation to the matter dominated phase so that they cannot contain topologically condensed matter. Before the condensation process the condensation of free cosmic strings gives rise to the gradual increase of the mass density of the critical cosmology.

This picture implies that cosmic expansion occurs only above some length scale and that the long length scale optical properties of the universe are determined by the competion of sub-cosmologies in hyperbolic and critical stages since photons travel along space-time sheets of both type.

4.3.4 p-Adic fractality

p-Adic fractality suggests that all cosmological phase transitions giving rise to the generation of new space-time sheets should be describable using the same universal Robertson-Walker cosmology during their critical period so that cosmology would contain cosmologies containing cosmologies... like Russian doll contains Russian dolls inside it. The light cone projection of each sub-cosmology is sub-light cone. Lorentz invariance requires that the probability distribution for the position the tip of the sub-light cone is constant along $a = constant$ hyperboloid.

Sub-cosmology is characterized by three parameters a_0, a_1 and a_2. a_0 characterizes the moment of birth for sub-cosmology, a_1 characterizes in excellent approximation the value of the sub-light cone proper time for which the transition from critical to hyperbolic sub-cosmology occurs. $a_1 + a_2$ in turn characterizes the sub-light cone proper time for the decay of the hyperbolic sub-cosmology to comoving non-expanding surfaces. p-Adic length scale hypothesis allows to make educated guesses for the values of a_0, a_1 and a_2 so that TGD inspired cosmology becomes highly predictive.

Since a_0 characterizes the moment of birth for sub-cosmology, it is not expected to reflect in any manner the dynamics of earlier sub-cosmologies. In contrast to this, a_1 and a_2 characterize the internal dynamics of sub-cosmology involving gravitational time dilation effects in an essential manner and this suggests that the fundamental parameters are the values of the proper times s_1 and s_2 for sub-cosmologies to which a_1 and a_2 are related in simple manner.

More quantitatively, the proper time s of the space-time surface representing cosmology is defined as

$$s = \int_0^a \sqrt{g_{aa}} da \quad .$$

The relationship between light cone proper time and proper time of the critical cosmology implies the relationship

$$\begin{aligned} s_1 &= \int_0^{a_1} \sqrt{1-K} da \quad , \\ K &\equiv \frac{R^2}{4a_1^2} \frac{1}{(1-(\frac{a}{a_1})^2)} \quad . \end{aligned} \tag{4.5}$$

between a_1 and s_1. Up to to $a \simeq a_1$ the value of the parameter K is nearly vanishing so that $s \simeq a$ holds in a good approximation during the critical period. This means that the values of s_1 and a_1 are in excellent approximation identical:

$$s_1 \simeq a_1 \quad .$$

The relationship between s_2 and a_1 and a_2 is

$$s_2 = \int_{a_1}^{a_1+a_2} \sqrt{g_{aa}}da \quad . \tag{4.6}$$

The gravitational dilation effects for hyperbolic cosmology are large and s_2 and a_2 can differ by orders of magnitude.

p-Adic length scale hypothesis states two things.

1. Each p-adic prime p corresponds to p-adic length scale $L_p = \sqrt{p} \times l$, where $l \simeq 10^{3.5}$ Planck lengths is CP_2 "radius".

2. The primes $p \simeq 2^k$, k prime or power of prime are physically preferred so that one has

$$L_p \equiv L(k) \simeq 2^{k/2} \times l \quad .$$

   p-Adic fractality allows to make educated guesses for the most plausible values of the parameters a_0, a_1 and a_2 characterizing the evolution of the sub-cosmologies.

1. Moments of birth of sub-cosmologies

It seems that the generation of new sub-cosmologies is a process having nothing to do with the internal dynamics of sub-cosmologies themselves. Therefore p-adic fractality suggests that the dips of the sub-light cones associated with the critical cosmologies are concentrated in good approximation at the hyperboloids

$$a_0(k) = x_0 L(k)$$

of the light cone M^4_+ where x_0 is some numerical constant: note that a_0 refers to the proper time of the light cone M^4_+ rather than sub-light cone. The number of primes k in the interval $[2, ..., 401]$ (see Table 2) is rather small which implies that the number of sub-cosmologies created after Big Bang is smaller than 100.

2. Moments for the transition to hyperbolicity

The natural guess is that the imbedding for the cosmology characterized by $p \simeq 2^k$ fails for $a \simeq a_1$ (in excellent approximation) when sub-cosmology also starts to metabolize the remnants of earlier sub-cosmologies. p-Adic length scale hypothesis gives the estimate

$$s_1(k) \simeq a_1(k) = x_1 L(k) \quad ,$$

where x_1 is numerical constant of order unity. The most natural interpretation is that transition to radiation or matter dominated cosmology occurs. It is natural to assume that topological condensation of 3-surfaces resulting from earlier cosmology accompanies this transition. One can also say that cosmological metabolism causes transition to hyperbolicity.

3. Moments of death for sub-cosmologies

The death of the sub-cosmology means decay to disjoint 3-surfaces. The simplest assumption is that this occurs when the age of sub-cosmology measured with respect to sub-cosmological proper time s exceeds p-adic time scale defined by the next p-adic prime in the hierarchy. Thus one has

$$s_1 + s_2 \simeq a_1 + s_2 = x_2 L(k(next))$$

giving

$$s_2 = x_2 L(k(next)) - x_1 L(k) \quad . \tag{4.7}$$

From this one can relate the parameter a_2 with the p-adic length scales $L(k(next)$ and $L(k)$. $L(k)$ gives the size scale of the 3-surfaces resulting when the connected space-time sheet $a_2 = constant$

decomposes to pieces. Due to gravitational time dilation s_2 can be smaller than a_2 by several orders of magnitude so that the duration of the hyperbolic period when measured using sub-light cone proper time is lengthened by gravitational time dilation and topological condensation of the remnants of sub-cosmology can take place to a critical cosmology having $k > k(next)$.

4. Temperature and energy density of the critical cosmology at the moment of transition to hyperbolicity.

p-Adic length scale hypothesis suggest that the temperature just after the transition to the effectively radiation dominated phase is

$$\begin{aligned} T(k) &= \frac{n}{L(k)} \ , \qquad \text{for } k > k_{cr} \ , \\ T(k) &= T_H \sim \frac{1}{R} \ , \quad \text{for } k \leq k_{cr} \ . \end{aligned} \tag{4.8}$$

Here n is rather large numerical factor. Since $a_F \sim 2.7 \times 10^{-10}$ seconds which corresponds to length scale $L \simeq .08$ meters roughly to p-adic length scale $L(197) \simeq .08$ meters (which by the way corresponds to the largest p-adic length scale associated with brain, cosmic joke?), should correspond to the establishment of Hagedorn temperature, one has the conditions

$$\begin{aligned} k_{cr} &= 197 \ , \\ n &\simeq 2^{197/2} \sim 10^{30} \sim \frac{m_{CP_2}^2}{m_p^2} \ . \end{aligned}$$

Thus n is in of same order of magnitude as the ratio of the CP_2 mass squared ($m_{CP_2} \simeq 10^{-3.5}$ Planck masses) to proton mass squared.

Dimensional considerations suggest also that the energy density in the beginning of the radiation dominated phase (in case that it is achieved) is

$$\rho = nT(k)^4 \ , \tag{4.9}$$

where n a numerical factor of order one. n does not count for the number of light particle species since the thermal energy of strings gives rise to the effective radiation dominance. This explains why infinite number of fermion families does not lead to infinite density of thermal energy and why their presence leaves no trace in present day cosmology.

When the time parameter a_1 of the critical cosmology becomes too high, it cannot anymore generate radiation dominated phase since the temperature remains too low. Previous considerations suggest that the maximum value of a_1 is roughly $a_1(max) = a_F \sim 3 \times 10^{-10}$. After this critical sub-cosmologies transform directly to the stationary cosmologies.

These estimates fix the structure of the fractal cosmology to rather high degree. Note that the expanding space-time surfaces associated with the new critical cosmologies created in the phase transition can fuse since corresponding light cones can intersect. The number of the phase transitions occurred after the light cone proper time corresponding to electron Compton length is roughly forty. The tables below give the p-adic length scales in the range extending from electron Compton radius to 10^{10} light years.

4.4 The Problem Of Cosmological Missing Mass

In inflationary cosmology the basic problem is related to the missing mass. The experimentally determined recent density of the ordinary matter is about 4 per cent of the critical mass density and it seems that ordinary sources (other than vacuum energy density) can contribute about 30 percent of the critical mass density in inflationary scenarios. In TGD framework the situation is different as following arguments show.

1. Criticality does not force missing mass in TGD framework.

There is no absolute need for vacuum energy density since the mass densities of critical cosmologies present in condensate are extremely low before the transition to the hyperbolicity. In TGD

Table 1: p-Adic length scales $L_p = 2^{k-151}L_{151}$, $p \simeq 2^k$, k prime, possibly relevant to astro- and biophysics. The last 3 scales are included in order to show that twin pairs are very frequent in the biologically interesting range of length scales. The length scale $L(151)$ is take to be thickness of cell scale, which is 10^{-8} meters in good approximation.

k	127	131	137	139	149
$L_p/10^{-10}m$	.025	.1	.8	1.6	50
k	151	157	163	167	169
$L_p/10^{-8}m$	1	8	64	256	512
k	173	179	181	191	193
$L_p/10^{-4}m$	.2	1.6	3.2	100	200
k	197	199	211	223	227
L_p/m	.08	.16	10	640	2560

Table 2: p-Adic length scales $L_p = 2^{(k-127)/2}L_{127}$, $p \simeq 2^k$, k prime, possibly relevant to large scale astrophysics. The definition of the length scale involves an unknown factor r of order one and the requirement $L(151) \simeq 10^{-8}$ meters, the thickness of the cell membrane, implies that this factor is $r \simeq 1.1$.

k	227	229	233	239	241
L_p/m	$2.3E+3$	$4.6E+3$	$1.9E+4$	$1.5E+5$	$3.0E+5$
k	251	257	263	269	271
L_p/m	$.96E+7$	$7.7E+7$	$6.0E+8$	$4.8E+9$	$.9E+10$
k	277	289	293	307	311
L_p/m	$7.7E+10$	$5.0E+12$	$2.0E+13$	$2.5E+15$	$1.0E+16$
k	313	317	329	331	337
L_p/ly	2.2	$5.4E+2$	$1.0E+3$	2.2E+3	$8.4E+3$
k	347	349	353	359	367
L_p/ly	$2.8E+5$	$5.6E+5$	$2.2E+6$	$1.8E+7$	$2.9E+8$
k	373	379	381	391	397
L_p/ly	$2.2E+9$	$1.9E+10$	3.8 E+10	1.2E+12	.96E+13

framework the observed mass density corresponds to the mass density at "our" cosmological space-time sheet condensed to some larger space-time sheet... condensed on the largest space-time sheet present in the topological condensate now. If the vapor phase density equals to the critical density of flat critical cosmology, the net energy density of the entire topological condensate is bound to be smaller than the critical density. This is in accordance with experimental facts. In fact, vapor phase energy density corresponds closely to the vacuum energy density of inflationary scenarios. By the conservation of energy the total energy density at various space-time sheets is indeed equal to "critical" vapor phase density apart from effects caused by different expansion rates. The possibility of negative energy virtual gravitons however makes possible for a given space-time sheet to have energy density much larger than the energy density of the vapor phase.

2. The observed optical properties of the Universe require that photons travel in critical cosmologies for a sufficiently long fraction of time.

The photons coming from a distant source must propagate along a space-time sheet of a critical cosmology for a sufficiently long fraction of time during their travel to detector. If the period of the matter dominance is too long, photons spend too long time fraction in matter dominated phase and the spectrum of anisotropies is seriously affected. This is avoided if the period between the initiation of the matter dominance and decomposition into disjoint 3-surfaces is sufficiently short. Generation of lumps of matter could in fact involve gravitational collapse leading to the decomposition of the 3-surface to pieces. Second possibility is that the topological condensation of photons is more probable on critical and essentially flat cosmologies (present always) than on matter dominated cosmologies. The large rate of topological evaporation from radiation and matter dominated cosmologies is consistent with this. An alternative explanation in terms of zero energy ontology is that topological evaporation is only effective.

3. The mass density of later matter dominated cosmologies should be larger than that of previous matter dominated cosmologies.

Assume that previous cosmology have made transition to non-expanding phase and behaves as comoving matter with density $\rho(p_1)$ on the next expanding matter dominated cosmology with density $\rho(p_2)$. Under this assumption the condition

$$\rho(p_1) \equiv p\rho(1) < \rho(p_2)$$

implies

$$a_1(p_1)\epsilon(p_1)\frac{1}{a^3(p_1)} = p \times a_1(p_2)\epsilon(p_2)\frac{1}{a^3(p_2)} \quad .$$

The larger the space-time sheet, the later it is created, and therefore one has $a(p_1) > a(p_2)$ as well as $a_1(p_1) < a_1(p_2)$. For large values of $a(p_1)$ and $a(p_2)$ one has $a(p_1) \sim a(p_2)$ in good approximation and one has

$$a_1(p_1)\epsilon(p_1) = p \times a_1(p_2)\epsilon(p_2) \quad . \tag{4.10}$$

The parameters ϵ are of order unity in recent day cosmology.

If one assumes the relationship $s_1 \simeq a_1 = xL(k)$, one obtains

$$\frac{\epsilon(k_1)}{\epsilon(k_2)} = p \times 2^{(k_2-k_1)/2} \quad . \tag{4.11}$$

It is possible to satisfy this constraint for $p < 1$.

The assumption about cosmologies inside cosmologies implies distribution of ages of the Universe and provides a natural explanation for why the observed mass density is subcritical. Cosmic strings topologically condensed at the larger space-time sheet could correspond to the missing mass. The age of the space-time sheet of an astrophysical object can be much longer than the age of the largest space-time sheet: this could explain the paradoxical observation that some stars seem to be older than the Universe.

4.5 TGD Based Explanation Of The Results Of The Balloon Experiments

TGD based model explaining the results of balloon experiments relies on the notion of the fractal cosmology.

4.5.1 Under what conditions Universe is effectively critical?

TGD based model explaining the results of balloon experiments relies on the notion of the fractal cosmology. If $a = constant$ sections of hyperbolic cosmologies decompose to disjoint 3-surfaces after sufficiently short matter dominated period, the photons propagating along these space-time sheets must "drop" on the critical space-time sheets so that situation stays effectively critical and model yields same predictions as inflationary cosmology. The decoupling of radiation from matter involved a topological phase transition leading to a generation of new expanding space-time sheets along which the CMB radiation could propagate.

The following argument shows under what conditions the total duration of the matter dominated periods is negligible as compared with the total duration of the critical periods. The ratio of the observed angular separation $\Delta\phi_{obs}$ between hot spots to real angular separation $\Delta\phi_r$ between them can be deduced from

$$\begin{aligned} \Delta\phi_{obs} \simeq tan(\Delta\phi_{obs}) &= \frac{\sqrt{g_{\phi\phi}}\Delta\phi_r}{R(r)} \ , \\ R(r) &= \int \sqrt{g_{aa}} da = \int \sqrt{g_{rr}} \frac{dr}{da} da \end{aligned} \tag{4.12}$$

$R(r)$ is the Euclidian distance calculated along the light like geodesic associated with photon and depends on the curvature properties of the intervening space. Flat cosmology serves as a natural reference and the ratio

$$\begin{aligned} \frac{\Delta\phi_{obs}}{\Delta\phi_{obs}(flat)} &= \frac{R(r,flat)}{R(r)} \\ &= \frac{a-a_1}{\int_{a_1}^{a} \sqrt{g_{aa}} da} \end{aligned} \tag{4.13}$$

measures the effect of the intervening space to the observed angular distance between hot spots of CMB. Note that the integral must be expressed in terms of the initial values of the coordinate r.

When photons travel along critical cosmology, $g_{aa} \simeq 1$ holds true and this corresponds to flat situation. For a fixed value of r one has the following approximate expressions in various cosmologies

$$\begin{aligned} & a - a_1 = r - r_1 \ , && \text{(critical cosmology with } g_{aa} = 1) \ , \\ & a - a_1 \sim log(\tfrac{r}{r_1}) \ , && \text{(hyperbolic cosmology with } g_{aa} = 1) \ , \\ & \tfrac{2}{3} ka((\tfrac{a}{a_R})^{1/2} - (\tfrac{a_1}{a_R})^{1/2}) && \\ & = log(\tfrac{r}{r_1}) \ , && \text{(matter dominance with } g_{aa} = k(\tfrac{a}{a_R})^{1/2}) \ . \end{aligned} \tag{4.14}$$

From these expressions one finds that same increment of r gives rise to much smaller increment of a in hyperbolic cosmology than in critical cosmology. Thus the fractions of r spent in critical cosmology gives the dominating contribution to the integral unless this fraction happens to be especially small. From these expressions one finds that for a given distance r the red shift in approximately flat (no horizon) hyperbolic cosmology is exponentially larger than in critical cosmology. The arrival of photons along hyperbolic cosmology could thus explain why their ages when derived from the red shift seem to be larger than the age of the Universe derived assuming that photons travel along critical cosmology.

During periods of matter dominance g_{aa} behaves as $g_{aa} = k\frac{a}{a_2}$ and gives smaller contribution than critical period. Integral can be expressed as sum of critical and matter dominated contributions as

$$\int_{a_2}^{a} \sqrt{g_{aa}}da = \sum_i \left[\Delta a_0(i) + s_2(i)\right] \quad . \tag{4.15}$$

Here the durations of periods are of order $L(k_i)$ and last period gives the dominant contribution. If the last propagation has occurred along critical cosmology for a sufficiently long time, the contribution of the earlier matter dominated periods to the integral are small and the last critical period can dominate in the integral. If the last critical period corresponds to $k = 379$ preceded by $k = 373$, then the ratio for angle separations does not differ more than about 10 per cent from the value guaranteeing ideal criticality.

4.5.2 What the absence of the second acoustic peak implies?

The absence of the second acoustic peak (which might be also a statistical artefact) fixes the TGD based model to a very high degree.

1. By quantum criticality scale free spectrum for the size L of the density fluctuations is a natural assumption when L is above the p-adic length scale $L(k(prev))$ characterizing the size of the remnants of the previous cosmology condensing to the critical space-time sheets in the transition to hyperbolic cosmology. Below this size ($L < L(k(prev))$) the spectrum for fluctuations has however natural cutoff. This cutoff could also correspond to the length of the cosmic strings giving rise to large voids containing cosmic strings inside them in TGD based model of galaxy formation and to the recent size of large voids containing galaxies at their boundaries. The space-time sheets of large voids should have been born in the phase transition generating CMB if this picture is correct.

2. The first acoustic maximum corresponds to $l = 200$ and $L(k_R)$. The second acoustic maximum corresponds to $l = 500$ and has thus size which is $2/5$ of the size of the first hot spot. $L(k_R(prev)$ defines the lower bound for the size of the density and temperature fluctuations as the minimum size of topologically condensed space-time sheets. Therefore, if second acoustic maximum is present, the size of the corresponding hot spot must be larger than $L(k_R(prev))$. Thus the condition for the absence of the second acoustic maximum is

$$\frac{L(k_R(prev))}{L(k_R)} < \frac{2}{5} \quad .$$

Thus the experimental absence of the second maximum requires that k_R and $k_R(prev)$ form twin pair ($k_R(prev) = k_R - 2$) so that one has $L(k_R(prev)) = L(k_R)/2$.

There are two candidates for the twin pairs in question: the twin pairs are $(347, 349)$ and $(359, 381)$ (see table 2 for the values of corresponding p-adic length scales). Only the first pair is consistent with the previous considerations related to p-adic fractality.

1. The pair ($k_R(prev) = 347, k_R = 349$) corresponds to the p-adic length scales $L(347) = 2.8E + 5$ ly and $L(349) = 5.6E + 5$ ly. $L(347)$ clearly corresponds to the minimum size of the first acoustic peak. Rather remarkably, the length scale $L(347)$, which corresponds also to the size of the typical spatial structures frozen in the transition to matter dominated cosmology, corresponds rather closely to the estimated time $s_R \sim 5E + 5$ years for the transition to matter dominance and also to the typical size of galaxies. In consistency with the general picture, the estimate

$$s_R = s_1 + s_2 = x_2 L(349)$$

gives $s_R = 5.8E + 5$ years for $x_2 = 1$.

2. If one takes seriously the order of magnitude estimate $s = s_R = 5 \times 10^5$ light years for the age of the cosmology when CMB was created, and assumes that hyperbolic cosmology was radiation dominated before s_R, one can estimate the value of light cone proper time a at this time using the formula

$$\begin{aligned} s_R &= \int_{a_1}^{a_R} \sqrt{g_{aa}} da \ , \\ g_{aa} &\simeq 10^{-3} \frac{a^2}{a_R^2} \ . \end{aligned} \tag{4.16}$$

This gives $a_R \sim 3.3 \times 10^7$ light years: this corresponds to the p-adic length scale $L(359)$. Thus gravitational time dilatation implies that topological condensation does not occur to $L(353)$ next to $L(349)$ but to $L(259)$. 5 new cosmologies corresponding to $k = 353, 359, 367, 373$ and 379 should have emerged after the transition to matter dominated cosmology and could correspond to cosmological structures. Large voids are certainly this kind of structures and correspond to the p-adic length scale $L(367) \sim 2.9E+8$ ly. The predicted age of the Universe is about $L(381) \sim 1.9E + 10$ years in this scenario.

4.5.3 Fluctuations of the microwave background as a support the notion of many-sheeted space-time

The fluctuations of the microwave background temperature are due to the un-isotropies of the mass density: enhanced mass density induces larger red shift visible as a local lowering of the temperature. Hence the fluctuations of the microwave temperatures spectrum provide statistical information about the deviations of the geometry of the 3-space from global homogenuity. The symmetries of the fluctuation spectrum can also provide information about the global topology of 3-space and for over-critical topologies the presence of symmetries is easily testable [E25].

The first year Wilkinson microwave anisotropy probe observations [E13] allow to deduce the angular correlation function. For angular separations smaller the 60 degrees the correlation function agrees well with that predicted by the inflationary scenarios and deriving essentially from the assumption of a flat 3-space (due to quantum criticality in TGD framework). For larger angular separations the correlations however vanish, which means the existence of a preferred length scale. The correlation function can be expressed as a sum of spherical harmonics. The $J = 1$ harmonic is not detectable due to the strong local perturbation masking it completely. The strength of $J = 2$ partial wave is only 1/7 of the predicted one whereas $J = 3$ strength is about 72 per cent of the predicted. The coefficients of higher harmonics agree well with the predictions based on infinite flat 3-space.

Later some interpretational difficulties have emerged: there is evidence that the shape of spectrum might reflect local conditions. There are differences between northern and southern galactic hemispheres and largest fluctuations are in the plane of the solar system. In TGD framework these anomalies could be interpreted as evidence for the presence of galactic and solar system space-time sheets.

1. Dodecahedral cosmology?

The WMAP result means a discrepancy with the inflationary scenario and explanations based on finite closed cosmologies necessarily having $\Omega > 1$ but very near to $\Omega = 1$ have been proposed. In [E16] Poincare dodecahedral space, which is globally homogenous space obtained by identifying the points of S^3 related by the action of dodecahedral group, or more concretely, by taking a dodecahedron in S^3 (12 faces, 20 vertices, and 30 edges) and identifying opposite faces after 36 degree rotation, was discussed. It was found to fit quadrupole and octupole strengths for $1.012 < \Omega < 1.014$ without an introduction of any other parameters than Ω.

However, according to [E18] the quadrupole and octupole moments have a common preferred spatial axis along which the spectral power is suppressed so that dodecahedron model seems to be excluded. The analysis of [E14] led to the same result. According to the article of Luminet [E21], the situation is however not yet completely settled, and there is even some experimental evidence for the predicted icosahedral symmetry of the thermal fluctuations.

The possibility to imbed also a very restricted family of over-critical cosmologies raises the question whether it might be possible to develop a TGD based version of the dodecahedral cosmology. The dodecahedral property could have two interpretations in TGD framework.

1. Space-time sheet with boundaries could correspond to a fundamental dodecahedron of S^3. If temperature fluctuations are assumed to be invariant under the so called icosahedral group, which is subgroup of $SO(3)$ leaving the vertices of dodecahedron invariant as a point set, the predictions of the dodecahedral model result.

2. An alternative interpretation is that the temperature fluctuations for S^3 decomposing to 120 copies of fundamental dodecahedron are invariant under the icosahedral group.

For neither option topological lensing phenomenon is present since icosahedral symmetry is not due to the identification of points of 3-space in widely different directions but due to symmetry which is not be strict. An objection against both options is that there is no obvious justification for the G invariance of the thermal fluctuations. The only justification that one can imagine is in terms of quantum coherent dark matter.

The finding of WMAP that the ratio Ω of the mass density of the Universe to critical mass density is $\Omega = 1 + g_{aa} = 1 + \epsilon$, $\epsilon = 0.02 \pm 02$. This is consistent with critical cosmology. If only slightly overcritical cosmology is realized, there must be a very good reason for this.

The WMAP constraint implies that the value of a which corresponds to the value of cosmic time a_s which characterizes the thermal fluctuations must be such that $g_{aa} = \epsilon$ holds true. The inspection of the explicit form of g_{aa} deduced in the subsection "Critical and over-critical cosmologies" requires that a_s is extremely near to the value a_0 of cosmic time for which $g_{aa} = 0$ holds true: the deviation of a from a_0 should be of order $(R/_0)R$ and most of the thermal radiation should have been generated at this moment.

Since gravitational mass density approaches infinity at $a \to a_0$ one can imagine that the spectrum of thermal fluctuations reflects the situation at the transition to sub-criticality occurring for $\Omega = 1 + \epsilon$. Thermal fluctuations would be identifiable as long ranged quantum critical fluctuations accompanying this transition and realized as a hierarchy of space-time sheets inducing the formation of structures. The scaling invariance of the fluctuation spectrum generalizes in TGD framework to conformal invariance. This means that the correlation function for fluctuations can have anomalous scaling dimension [E7]. The hadron physics analogy would be the transition from hadronic phase to quark gluon plasma via a critical phase discussed in section "Simulating Big Bang in laboratory".

The transition $k = 1 \to 0 \to -1$ would involve the change in the shape of the $S^2 \subset CP_2$ angle coordinate Φ as a function $f(r)$ of radial coordinate of RW cosmology. The shape is fixed by the value of $k = 1, 0, -1$. In particular, Φ would become constant in the transition to subcriticality. $k = 1 \to 0$ phase transition would be accompanied by the increase of the maximal size of space-time sheets to infinite in accordance with the emergence of infinite quantum coherence length at criticality. Whether this could be regarded as the TGD counterpart for the exponential expansion during inflationary period is an interesting question. In the transition to subcriticality also the shape of Θ as function of a necessarily changes since $sin(\Theta(a > a_0)) > 1$ would be required otherwise.

2. Hyperbolic cosmology with finite volume?

Also hyperbolic cosmologies allow infinite number of non-simply connected variants with 3-space having finite volume. For these cosmologies the points of $a = constant$ hyperboloid are identified under some discrete subgroup G of $SO(3, 1)$. Also now fundamental domain determines the resulting space and it has a finite volume.

It has been found that a hyperbolic cosmology with finite-sized 3-space based on so called Picard hyperbolic space [E12, E26] , which in the representation of hyperbolic space H^3 as upper half space $z > 0$ with line element $ds^2 = (dx^2 + dy^2 + dz^2)/z^2$ can be modeled as the space obtained by the identifications $(x, y, z) = (x + ma, y + nb, z)$. This space can be regarded as an infinitely long trumpet in z-direction having however a finite volume. The cross section is obviously 2-torus. This metric corresponds to a foliation of H^3 represented as hyperboloid of M^4 by surfaces $m^3 = f(\rho)$,

$\rho^2 = (m^1)^2 + (m^2)^2$ with f determined from the requirement that the induced metric is flat so that x, y correspond to Minkowski coordinates (m^1, m^2) and z a parameter labeling the flat 2-planes corresponds to m^3 varying from ∞ to ∞.

This model allows to explain the small intensities of the lowest partial waves as being due to constraints posed by G invariance but requires $\Omega = .95$. This is not quite consistent with $\Omega = 1.02 \pm .02$.

Also now two interpretations are possible in TGD framework. Thermal photons could originate from a space-time sheet identifiable as the fundamental domain invariant under G. Alternatively, $a = constant$ hyperboloid could have a lattice-like structure having fundamental domain as a lattice cell with thermal fluctuations invariant under G. The shape of the fundamental domain interpreted as a surface of M^4 is rather weird and one could argue that already this excludes this model.

Quantum criticality and the presence of quantum coherent dark matter in arbitrarily long length scales could explain the invariance of fluctuations. If Ω reflects the situation after the transition to subcriticality, one has $\Omega = g_{aa} - 1 = .95$. This gives $g_{aa} = 1.95$ which is in conflict with $g_{aa} < 1$ holding true for the imbeddings of all hyperbolic cosmologies. Thus Ω must correspond to the critical period and one should explain the deviation from $\Omega = 1$. A detailed model for the temperature fluctuations possibly fixed by conformal invariance alone would be needed in order to conclude whether many-sheeted space-time might allow this option.

3. Is the loss of correlations due to the finite size of the space-time sheet?

One can imagine a much more concrete explanation for the vanishing of the correlations at angles larger than 60 degrees in terms of the many-sheeted space-time. Large angular separations mean large spatial distances. Too large spatial distance, together with the fact that the size of the space-time sheet containing the two astrophysical objects was smaller than now, means that they cannot belong to the same space-time sheet if the red shift is large enough, and cannot thus correlate. The size of the space-time sheet defines the preferred scale. The preferred direction would be most naturally defined by cosmic string(s) in the length scale of the space-time sheet. For instance, closed cosmic string would define an expanding 3-space with torus topology and thus having symmetries. This option would explain also the WMAP anomalies suggesting local effects as effects due to galactic and solar space-time sheets.

4.5.4 Empirical support for the hyperbolic period

TGD inspired cosmology predicts that critical cosmology is followed by a hyperbolic cosmology. A natural question is whether the travel of microwave photons through the negative curvature cosmology might induce some signatures in microwave background. This is indeed the case.

The geodesics in negative curvature 3-space diverge exponentially. The divergence of the nearly parallel light-like geodesic lines is due to the negative curvature making 2-dimensional sections of 3-space analogous to saddle surfaces. The scatterings during the travel of light induce geodesic mixing so that light from regions with differing temperature mix. Hence negative curvature tends to smooth out the anisotropies of the temperature distribution.

Negative curvature has also a more dramatic signature. Gurzadyan [E20, E31] has developed a very refined argument involving algorithmic information theory and complexity theory to show that in the hyperbolic cosmology the hot and cold spots of the temperature distribution of the cosmic microwave radiation look elongated. The direction of elongation is random but the shape of the ellipse is characterized by the curvature of 3-space and does not depend on temperature or size of the spot. For a flat or positively curved space this kind of elongation does not occur.

The emergence of a preferred direction in a Lorentz invariant cosmology looks highly counter-intuitive. My humble understanding is that a scattering of photons from a large geometric structure must be involved somehow. The elongation should relate to what happens at the last scattering surface whose position together with the positions of observer and previous scattering surface define a plane whose normal defines the preferred direction, which would presumably correspond to the shorter axis of the ellipse. In TGD framework the transfer of photons from a larger space-time sheet to that of observer might correspond to this scattering process. Scattering surface would correspond to the boundary of the space-time sheet of the observer whereas scattering would correspond to refraction at the boundary.

The analysis of BOOMERanG, COBE and WMAP CMB maps indeed shows that the spots have elliptic shape with ellipticity parameter ~ 2 whereas the prediction for hyperbolic RW cosmology is 1.4. [E15]. This would suggest that some additional effect is involved and TGD inspired bet have been already described.

5 Inflation And TGD

The comparison of TGD with inflationary cosmology combined with new results about TGD inspired cosmology provides fresh insights to the relationship of TGD and standard approach and shows how TGD cures the lethal diseases of the eternal inflation. Very roughly: the replacement of the energy of the scalar field with magnetic energy replaces eternal inflation with a fractal quantum critical cosmology allowing to see more sharply the TGD counterpart of inflation and accelerating expansion as special cases of criticality. Wikipedia gives a nice overall summary inflationary cosmology [E2] and I recommend it to the non-specialist physics reader as a manner to refresh his or her memory.

5.1 Brief Summary Of The Inflationary Scenario

Inflationary scenario relies very heavily on rather mechanical unification recipes based on GUTs. Standard model gauge group is extended to a larger group. This symmetry group breaks down to standard model gauge group in GUT scale which happens to correspond to CP_2 size scale. Leptons and quarks are put into same multiplet of the gauge group so that enormous breaking of symmetries occurs as is clear from the ratio of top quark mass scale and neutrino mass scale. These unifiers want however a simple model allowing to calculate so that neither aesthetics nor physics does not matter. The instability of proton is one particular prediction. No decays of proton in the predicted manner have been observed but this has not troubled the gurus. As a matter fact, even Particle Data Tables tell that proton is not stable! The lobbies of GUTs are masters of their profession!

One of the key features of GUT approach is the prediction Higgs like fields. They allow to realize the symmetry breaking and describe particle massivation. Higgs like scalar fields are also the key ingredient of the inflationary scenario and inflation goes to down to drain tub if Higgs is not found at LHC. It is looking more and more probable that this is indeed the case. Inflation has endless variety of variants and each suffers from some drawback. In this kind of situation one would expect that it is better to give up but it has become a habit to say that inflation is more that a theory, it is a paradigm. When superstring models turned out to be a physical failure, they did not same thing and claimed that super string models are more like a calculus rather than mere physical theory.

5.1.1 The problems that inflation was proposed to solve

The basic problems that inflation was proposed to solve are magnetic monopole problem, flatness problem, and horizon problem. Cosmological principle is a formulation for the fact that cosmic microwave radiation is found to be isotropic and homogenous in an excellent approximation. There are fluctuations in CMB believed to be Gaussian and the prediction for the spectrum of these fluctuations is an important prediction of inflationary scenarios.

1. Consider first the horizon problem. The physical state inside horizon is not causally correlated with that outside it. If the observer today receives signals from a region of past which is much larger than horizon, he should find that the universe is not isotropic and homogenous. In particular, the temperature of the microwave radiation should fluctuate wildly. This is not the case and one should explain this.

   The basic idea is that the potential energy density of the scalar field implies exponential expansion in the sense that the "radius" of the Universe increases with an exponential rate with respect to cosmological time. This kind of Universe looks locally like de-Sitter Universe. This fast expansion smooths out any inhomogenuities and non-isotropies inside horizon. The Universe of the past observed by a given observer is contained within the horizon of the past so that it looks isotropic and homogenous.

2. GUTs predict a high density of magnetic monopoles during the primordial period as singularities of non-abelian gauge fields. Magnetic monopoles have not been however detected and one should be able to explain this. The idea is very simple. If Universe suffers an exponential expansion, the density of magnetic monopoles gets so diluted that they become effectively non-existent.

3. Flatness problem means that the curvature scalar of 3-space defined as a hyper-surface with constant value of cosmological time parameter (proper time in local rest system) is vanishing in an excellent approximation. de-Sitter Universe indeed predicts flat 3-space for a critical mass density. The contribution of known elementary particles to the mass density is however much below the critical mass density so that one must postulate additional forms of energy. Dark matter and dark energy fit the bill. Dark energy is very much analogous to the vacuum energy of Higgs like scalar fields in the inflationary scenario but the energy scale of dark energy is by 27 orders of magnitude smaller than that of inflation, about 10^{-3} eV.

5.1.2 Evolution of inflationary models

The inflationary models developed gradually more realistic.

1. Alan Guth was the first to realize that the decay of false (unstable) vacuum in the early universe could solve the problem posed by magnetic monopoles. What would happen would be the analog of super-cooling in thermodynamics. In super-cooling the phase transition to stable thermodynamical phase does not occur at the critical temperature and cooling leads to a generation of bubbles of the stable phase which expand with light velocity.

   The unstable super-cooled phase would locally correspond to exponentially expanding de-Sitter cosmology with a non-vanishing cosmological constant and high energy density assignable to the scalar field. The exponential expansion would lead to a dilution of the magnetic monopoles and domain walls. The false vacuum corresponds to a value of Higgs field for which the symmetry is not broken but energy is far from minimum. Quantum tunnelling would generate regions of true vacuum with a lower energy and expanding with a velocity of light. The natural hope would be that the energy of the false vacuum would generate radiation inducing reheating. Guth however realized that nucleation does not generate radiation. The collisions of bubbles do so but the rapid expansion masks this effect.

2. A very attractive idea is that the energy of the scalar field transforms to radiation and produces in this manner what we identify as matter and radiation. To realize this dream the notion of slow-roll inflation was proposed. The idea was that the bubbles were not formed at at all but that the scalar field gradually rolled down along almost flat hill. This gives rise to an exponential inflation in good approximation. At the final stage the slope of the potential would come so steep that reheating would took place and the energy of the scalar field would transform to radiation. This requires a highly artificial shape of the potential energy. There is also a fine tuning problem: the predictions depend very sensitively on the details of the potential so that strictly speaking there are no predictions anymore. Inflaton should have also a small mass and represent new kind of particle.

3. The tiny quantum fluctuations of the inflaton field have been identified as the seed of all structures observed in the recent Universe. These density fluctuations make them visible also as fluctuations in the temperature of the cosmic microwave background and these fluctuations have become an important field of study (WMAP).

4. In the hybrid model of inflation there are two scalar fields. The first one gives rise to slow-roll inflation and second one puts end to inflationary period when the first one has reached a critical value by decaying to radiation. It is of course imagine endless number of speculative variants of inflation and Wikipedia article summarizes some of them.

5. In eternal inflation the quantum fluctuations of the scalar field generate regions which expand faster than the surrounding regions and gradually begin to dominate. This means that there is eternal inflation meaning continual creation of Universes. This is the basic idea behind multiverse thinking. Again one must notice that scalar fields are essential: in absence of them the whole vision falls down like a card house.

The basic criticism of Penrose against inflation is that it actually requires very specific initial conditions and that the idea that the uniformity of the early Universe results from a thermalization process is somehow fundamentally wrong. Of course, the necessity to assume scalar field and a potential energy with a very weird shape whose details affect dramatically the observed Universe, has been also criticized.

5.2 Comparison With TGD Inspired Cosmology

It is good to start by asking what are the empirical facts and how TGD can explain them.

5.2.1 What about magnetic monopoles in TGD Universe?

Also TGD predicts magnetic monopoles. CP_2 has a non-trivial second homology and second geodesic sphere represents a non-trivial element of homology. Induced Kähler magnetic field can be a monopole field and cosmic strings are objects for which the transversal section of the string carries monopole flux. The very early cosmology is dominated by cosmic strings carrying magnetic monopole fluxes. The monopoles do not however disappear anywhere. Elementary particles themselves are string like objects carrying magnetic charges at their ends identifiable as wormhole throats at which the signature of the induced metric changes. For fermions the second end of the string carries neutrino pair neutralizing the weak isospin. Also color confinement could involve magnetic confinement. These monopoles are indeed seen: they are essential for both the screening of weak interactions and for color confinement!

5.2.2 The origin of cosmological principle

The isotropy and homogenuity of cosmic microwave radiation is a fact as are also the fluctuations in its temperature as well as the anomalies in the fluctuation spectrum suggesting the presence of large scale structures. Inflationary scenarios predict that fluctuations correspond to those of nearly gauge invariant Gaussian random field. The observed spectral index measuring the deviation from exact scaling invariance is consistent with the predictions of inflationary scenarios.

Isotropy and homogenuity reduce to what is known as cosmological principle. In general relativity one has only local Lorentz invariance as approximate symmetry. For Robertson-Walker cosmologies with sub-critical mass density one has Lorentz invariance but this is due to the assumption of cosmological principle - it is not a prediction of the theory. In inflationary scenarios the goal is to reduce cosmological principle to thermodynamics but fine tuning problem is the fatal failure of this approach.

In TGD inspired cosmology [K19] cosmological principle reduces sub-manifold gravity in $H = M^4 \times CP_2$ predicting a global Poincare invariance reducing to Lorentz invariance for the causal diamonds. This represent extremely important distinction between TGD and GRT. This is however not quite enough since it predicts that Poincare symmetries treat entire partonic 2-surfaces at the end of CD as points rather than affecting on single point of space-time. More is required and one expects that also now finite radius for horizon in very early Universe would destroy the isotropy and homogenuity of 3 K radiation. The solution of the problem is simple: cosmic string dominated primordial cosmology has infinite horizon size so that arbitrarily distance regions are correlated. Also the critical cosmology, which is determined part from the parameter determining its duration by its imbeddability, has infinite horizon size. Same applies to the asymptotic cosmology for which curvature scalar is extremized.

The hierarchy of Planck constants [K11] and the fact that gravitational space-time sheets should possess gigantic Planck constant suggest a quantum solution to the problem: quantum coherence in arbitrary long length scales is present even in recent day Universe. Whether and how this two views about isotropy and homogenuity are related by quantum classical correspondence, is an interesting question to ponder in more detail.

5.2.3 Three-space is flat

The flatness of three-space is an empirical fact and can be deduced from the spectrum of microwave radiation. Flatness does not however imply inflation, which is much stronger assumption involving the questionable scalar fields and the weird shaped potential requiring a fine tuning. The already mentioned critical cosmology is fixed about the value value of only single parameter characterizing its duration and would mean extremely powerful predictions since just the imbeddability would fix the space-time dynamics almost completely.

Exponentially expanding cosmologies with critical mass density do not allow imbedding to $M^4 \times CP_2$. Cosmologies with critical or over-critical mass density and flat 3-space allow imbedding but the imbedding fails above some value of cosmic time. These imbeddings are very natural since the radial coordinate r corresponds to the coordinate r for the Lorentz invariant a=constant hyperboloid so that cosmological principle is satisfied.

Can one imbed exponentially expanding sub-critical cosmology? This cosmology has the line element

$$ds^2 = dt^2 - ds_3^2 \ , \ ds_3^2 = sinh^2(t)d\Omega_3^2 \ ,$$

where ds_3^2 is the metric of the $a = constant$ hyperboloid of M_+^4 (future light-cone).

1. The simplest imbedding is as vacuum extremal to $M^4 \times S^2$, S^2 the homologically trivial geodesic sphere of CP_2. The imbedding using standard coordinates (a, r, θ, ϕ) of M_+^4 and spherical coordinates (Θ, Φ) for S^2 is to a geodesic circle (the simplest possibility)

$$\Phi = f(a) \ , \ \Theta = \pi/2 \ .$$

2. $\Phi = f(a)$ is fixed from the condition

$$a = sinh(t) \ ,$$

giving

$$g_{aa} = (dt/da)^2 = \frac{1}{cosh^2(t)}$$

and from the condition for the g_{aa} as a component of induced metric tensor

$$g_{aa} = 1 - R^2(\frac{df}{da})^2 = \frac{1}{cosh^2(t)} \ .$$

3. This gives

$$\frac{df}{da} = \pm \frac{1}{R} \times tanh(t)$$

giving $f(a) = (cosh(t) - 1)/R$. Inflationary cosmology allows imbedding but this imbedding cannot have a flat 3-space and therefore cannot make sense in TGD framework.

5.2.4 Replacement of inflationary cosmology with critical cosmology

In TGD framework inflationary cosmology is replaced with critical cosmology. The vacuum extremal representing critical cosmology is obtained has 2-D CP_2 projection- in the simplest situation geodesic sphere. The dependence of Φ on r and Θ on a is fixed from the condition that one obtains flat 3- metric

$$\frac{a^2}{1+r^2} - R^2 sin^2(\Theta)(\frac{d\Phi}{dr})^2 = a^2 \ .$$

This gives

$$sin(\Theta) = \pm ka \ , \ \frac{d\Phi}{dr} = \pm \frac{1}{kR}\frac{r}{\sqrt{1+r^2}} \ .$$

The imbedding fails for $|ka| > 1$ and is unique apart from the parameter k characterizing the duration of the critical cosmology. The radius of the horizon is given by

$$R = \int \frac{1}{a}\sqrt{1 - \frac{R^2k^2}{1-k^2a^2}}$$

and diverges. This tells that there are no horizons and therefore cosmological principle is realized. Infinite horizon radius could be seen as space-time correlate for quantum criticality implying long range correlations and allowing to realize cosmological principle. Therefore thermal realization of cosmological principle would be replaced with quantum realization in TGD framework predicting long range quantal correlations in all length scales. Obviously this realization is a in well-defined sense the diametrical opposite of the thermal realization. The dark matter hierarchy is expected to correspond to the microscopic realization of the cosmological principle generating the long range correlations.

Critical cosmology could describe the phase transition increasing Planck constant associated with a magnetic flux tube leading to its thickening. Magnetic flux would be conserved and the magnetic energy for the thicknened portion would be reduced via its partial transformation to radiation giving rise to ordinary and dark matter.

5.2.5 Fractal hierarchy of cosmologies within cosmologies

Many-sheeted space-time leads to a fractal hierarchy of cosmologies within cosmologies. In zero energy ontology the realization is in terms of causal diamonds within causal diamonds with causal diamond identified as intersection of future and past directed light-cones. One can say that everything can be created from vacuum. The temporal distance between the tips of CD is given as an integer multiple of CP_2 time in the most general case and boosts of CDs are allowed. The are also other moduli associated with CD and discretization of the moduli parameters is strong suggestive.

Critical cosmology corresponds to negative value of "pressure" so that it also gives rise to accelerating expansion. This suggests strongly that both the inflationary period and the accelerating expansion period which is much later than inflationary period correspond to critical cosmologies differing from each other by scaling. Continuous cosmic expansion is replaced with a sequence of discrete expansion phases in which the Planck constant assignable to a magnetic flux quantum increases and implies its expansion. This liberates magnetic energy as radiation so that a continual creation of matter takes place in various scales.

This fractal hierarchy is the TGD counterpart for the eternal inflation. This fractal hierarchy implies also that the TGD counterpart of inflationary period is just a scaled up invariant of critical cosmologies within critical cosmologies. Of course, also radiation and matter dominated phases as well as asymptotic string dominated cosmology are expected to be present and correspond to cosmic evolutions within given CD.

5.2.6 Vacuum energy density as magnetic energy of magnetic flux tubes and accelerating expansion

TGD allows a more microscopic view about cosmology based on the vision that primordial period is dominated by cosmic strings which during cosmic evolution develop 4-D M^4 projection meaning that the thickness of the M^4 projection defining the thickness of the magnetic flux tube gradually increases [K19]. The magnetic tension corresponds to negative pressure and can be seen as a microscopic cause of the accelerated expansion. Magnetic energy is in turn the counterpart for the vacuum energy assigned with the inflaton field. The gravitational Planck constant assignable to the flux tubes mediating gravitational interaction nowadays is gigantic and they are thus in macroscopic quantum phase. This explains the cosmological principle at quantum level.

The phase transitions inducing the boiling of the magnetic energy to ordinary matter are possible. What happens that the flux tube suffers a phase transition increasing its radius. This however reduces the magnetic energy so that part of magnetic energy must transform to ordinary matter. This would give rise to the formation of stars and galaxies. This process is the TGD counterpart for the re-heating transforming the potential energy of inflaton to radiation. The local expansion of the magnetic flux could be described in good approximation by critical cosmology since quantum criticality is in question.

One can of course ask whether inflationary cosmology could describe the transition period and critical cosmology could correspond only to the outcome. This does not look very attractive idea since the CP_2 projections of these cosmologies have dimension D=1 and D=2 respectively.

In TGD framework the fluctuations of the cosmic microwave background correspond to mass density gradients assignable to the magnetic flux tubes. An interesting question is whether the flux tubes could reveal themselves as a fractal network of linear structures in CMB. The prediction is that galaxies are like pearls in a necklace: smaller cosmic strings around long cosmic strings. The model discussed for the formation of stars and galaxies discussed in the previous section gives a more detailed view about this.

5.2.7 What is the counterpart of cosmological constant in TGD framework?

In TGD framework cosmological constant emerge when one asks what might be the GRT limit of TGD [K21], [L1] (see `http://tinyurl.com/hzkldnb`). Space-time surface decomposes into regions with both Minkowskian and Euclidian signature of the induced metric and Euclidian regions have interpretation as counterparts of generalized Feynman graphs. Also GRT limit must allow space-time regions with Euclidian signature of metric - in particular CP_2 itself - and this requires positive cosmological constant in this regions. The action principle is naturally Maxwell-Einstein action with cosmological constant which is vanishing in Minkowskian regions and very large in Euclidian regions of space-time. Both Reissner-Nordström metric and CP_2 are solutions of field equations with deformations of CP_2 representing the GRT counterparts of Feynman graphs. The average value of te cosmological constant is very small and of correct order of magnitude since only Euclidian regions contribute to the spatial average. This picture is consistent with the microscopic picture based on the identification of the density of magnetic energy as vacuum energy since Euclidian particle like regions are created as magnetic energy transforms to radiation.

5.2.8 Dark energy and cosmic consciousness

The hierarchy of Planck constants makes possible macroscopic quantum coherence in arbitrarily long scales. Macroscopic quantum coherence is essential for life and the notion of magnetic body is central in TGD inspired biology. For instance, the braiding of flux tubes making possible topological quantum computation like processes [K10]. The findings of Peter Gariaev [?, ?, ?] provide support for the notion of magnetic body containing dark matter [K1]. The notion of magnetic body also inspires science fictive ideas like remote replication of DNA [K29] for which there is also some support and which could be essential for understanding water memory [?, ?].

The gravitational Planck constant $\hbar_{gr} = GM_1M_2/v_0$ (v_0 is dimensionless parameter in units for which $c = 1$ but has interpretation as velocity) assumed in the model of planetary system based on Bohr orbitology [K18, K16] is assigned to the magnetic flux quanta mediating gravitational interaction between objects with masses M_1 and M_2 ($M_1 = M_2$ for self gravitation). For these values of Planck constant the quantum scales are gigantic. Even for gravitational magnetic flux tubes connecting electron with Sun, the Compton length would be of the order of the radius of Sun. If there are ordinary particles at these flux tubes, their Compton length is enormous and their density is essentially constant.

The fractality of TGD Universe and of the magnetic flux tube hierarchy forces to ask whether intelligent consciousness could be possible in cosmic scales and be based on the Indra's net of the magnetic flux tubes. This cosmic nervous system would carry dark energy as magnetic energy with magnetic tension responsible for the negative "pressure" causing accelerated expansion. This Indra's web would act as super-intelligence taking the role of God by creating stars and galaxies by transforming magnetic energy to radiation and matter in phase transitions increasing the Planck constant and driving the evolution of this cosmic intelligence. In inflationary scenario inflaton field would have similar role. In zero energy ontology there is no deep reason preventing for the creation of entire sub-cosmologies from vacuum.

6 Bicep2 Might Have Detected Gravitational Waves

BICEP2 team [E28] has announced a detection of gravitational waves via the effects of gravitational waves on the spectrum on polarization of cosmic microwave background (CMB). What happens that gravitational waves (or possibly some other mechanism) transforms so called E modes which correspond the curl free part of polarization field expressible as gradient to B modes responsible for the divergenceless part of polarization field expressible as curl of vector field.

Interaction of photons with gravitons would induce this polarization changing transformation: this is discussed in earlier post by Lubos Motl. The signal is unexpectedly strong constraints on possible models, in particular to the inflationary models which are currently in fashion. The map produced by BICEP describes the vorticity of the polarization field at the sky and one can clearly see it (`https://lh6.googleusercontent.com/-0PI9pZ7FImM/UycduxUJ3HI/AAAAAAAAAG7w/uDlbGCe7ASM/bicep2-b_over_b_rect_BICEP2.png?imgmax=1600`).

There has been a lot of pre-hype about the finding as proof for inflation, which it is not. Even Scientific American falls in the sin of inflationary hyping: inflationary theory is only the dominating theory which might be able to explain the finding.

In the sequel the findings are discussed in the framework of TGD based cosmology in which the flatness of 3-space is interpreted in terms of quantum criticality rather than inflation. The key role is played by gradually thickening cosmic strings carrying magnetic monopole flux, dark energy as magnetic energy and dark matter as large h_{eff} phases at cosmic strings. Very thin cosmic strings dominate the cosmology before the emergence of space-time as we know it and quantum criticality is associated with the phase transition between these two phases. Later cosmic strings serve as seeds of various cosmological structures by decaying partially to ordinary matter somewhat like inflaton fields in inflationary cosmology. Cosmic strings also explain the presence of magnetic fields in cosmos difficult to understand in standard approch. The crucial point is that - in contrast to ordinary magnetic fields - monopole fluxes do not require for their creation any currents coherent in long scales.

6.1 Liam Mcallister's Summary About The Findings Of Bicep2 Team

Liam McAllister from Cornell University has written an excellent posting about the discovery and its implications in Lubos Motl's blog [E22]. McAllister discusses the finding from several points of view. Can one trust that the finding is real? How should one interpret the result? What are its implications? A brief summary is in order before going to details.

1. Consideration is restricted to inflationary scenarios but it is made clear that they are not the only option. It is emphasized that a huge amount of inflationary parameter space is excluded by the unexpectedly high strength of the effect. Also the general problems of inflationary models are made explicit - a great favor for those who are not inflationary enthusiasts and might have something else in mind.

2. Also other than gravitonic mechanisms transforming E modes to B modes can be imagined. For instance, the signal might not be primordial but caused by polarized foreground sources: BICEP claims that these contributions have been eliminated.

3. The most important conclusion is of course that a direct detection of gravitational waves - maybe even quantal ones - has been achieved. Earlier gravitational radiation has been detected only a slowing down of rotation rate of pulsars (Hulse-Taylor binary pulsar).

6.2 Comparison Of Inflationary Models And TGD

Further conclusions depend on the cosmological model adopted and McAllister considers the situation in the framework of inflationary models and lists the basic aspects of inflationary model.

1. The Universe on large scales should be approximately homogenous, isotropic and flat.

2. The primordial scalar density perturbations should be correlated on super-horizon scales and be approximately Gaussian, adiabatic, and approximately scale-invariant.

In TGD framework inflationary cosmology is replaced with a cosmology fixed almost uniquely by the criticality of the mass density when combined with imbeddability to $N^4 \times CP_2$ as Lorentz invariant 4- surface [K21, K19]. The only free parameter is the finite duration τ of the critical period. This kind of critical - it seems even quantum critical - periods are predicted to appear in various scales so that Russian doll cosmology is strongly suggested as in case of inflationary models. Scalar fields (inflaton fields) are replaced with cosmic strings, which evolve by thickening their M^4 projections from string world sheets to 4-D ones. Magnetic energy replaces dark energy and has interpretation as counterpart for the energy of inflation field. Dark matter at magnetic flux tubes corresponds to large $\hbar$ phases [K11, K18, K16].

1. In TGD framework the long range correlations would be due to quantum criticality rather than extremely rapid expansion during inflationary period. The Universe in large scales should be also now homogenous, isotropic, and flat.

2. The primordial density perturbations reflect the presence of cosmic strings before the phase transition period. These cosmic strings have 2-D M^4 projection, which is minimal surface, so that these object behave for all practical purposes like strings, and CP_2 projection is e 2-D holomorphic surface in CP_2. During primordial period cosmic strings dominate and the mass density behaves like $1/a^2$, where a is proper time coordinate of the light-cone. The mass per comoving volume goes to zero at the moment of big bang so that initial singularity is smoothed out and big bang transforms to "a silent whisper amplified to big bang". For radiation dominated cosmology mass density would behave as $1/a^4$ giving rise to infinite energy per comoving volume at the moment of Big Bang.

3. Cosmic strings gradually thicken their M^4 projections and the huge primordial magnetic fields carrying quantized monopole flux weaken. These fields differ crucially from the ordinary magnetic fields in that no current is needed to create them - this is due the fact that CP_2 Kähler form defines a self-dual magnetic monopole (instanton). Amazingly, even the magnetic fields penetrating to super-conductors could be this kind and perhaps even those associated with ferromagnets.

   This can explain why primordial and recent Universe is full of magnetic fields in length scales, where they should not exist since the currents creating them cannot exist in long scales. The thickening of the remnants of cosmic strings would give rise to birth of galaxies organised like pearls in necklace along big cosmic strings: galaxies are indeed known to be organized into long string like structures and density perturbations would correspond to these strings.

   No vacuum expectations of Higgs like scalar fields are needed. Even in elementary particle physics Higgs expectation is replaced with string tension assignable to string like structures accompanying elementary particles.

   Cosmic strings would carry dark energy as magnetic energy and dark matter as phases with large values of Planck constant coming as integer multiple of ordinary Planck constant. Ordinary matter would be formed when cosmic strings and dark matter "burn" to ordinary matter: this would be the TGD counterpart for the decay of inflaton field to ordinary matter.

4. Cosmic strings would define the density perturbations having correlations on super-horizon scales. In the first approximation they are certainly Gaussian. Whether they are adiabatic (no exchange of heat with environment) is an interesting question: if they correspond to large values of Planck constant, this is certainly what one expects. The perturbations would be approximately scale invariant: p-adic length scale hypothesis would formulate this quantitatively by replacing continuum of scales with a hierarchy of discrete p-adic length scales coming as powers of square root of 2 (half octaves).

5. One can of course ask about spectrum of Planck constant coming as integer multiples of ordinary Planck constant: could it realize the presence of large number of length scales characterizing criticality? Could the spectrum of length scales implied by spectrum of Planck constants be the TGD counterpart for the inflationary expansion? Does the average value of Compton length or flux tube length proportional to h_{eff} increase with exponential rate during quantum criticality as larger and larger Planck constants emerge?

It seems that at this qualitative level TGD survives basic tests at qualitative level but without assuming inflation fields and exponentially fast expansion since quantum criticality predicting flat 3-space (dimensional parameters such as curvature of 3-space vanish). Cosmic strings would represent the long range fluctuations. A further bonus is that cosmic strings explain dark energy and dark matter, and also the presence of long range magnetic fields in cosmos.

6.3 Fluctuations Of Gravitational Field

McAllister gives a nice overall summary about the physics involved if given by inflationary models.

1. It is not yet fully clear whether the fluctuations of gravitational field are quantum mechanical or classical. In TGD framework quantum classical correspondence suggests that quantal and classical identifications might be equivalent.

2. Just as the quantum fluctuations of inflaton field would give rise to the density fluctuations visible as temperature anisotropies and large scale structures, the quantum fluctuations of gravitational field would give rise to the observed B modes in inflationary scenario. The correlation functions of gravitons in the background metric would tell everything. The problem is that we do not yet have quantum theory of gravitation allowing to really calculate everything except in QFT approximation.

3. In TGD framework the fluctuations should physically correspond to cosmic strings and the question is whether gravitons can be identified as massless modes for the cosmic strings so that string like objects would give all. In fact, elementary particles are in TGD framework identified as string like objects! Ironically, TGD as generalization of string model realizes stringy dream in all scales and even for ordinary elementary particles!

Since gravitons couple to energy the formula for the energy density at which inflationary period begins should determine the spectrum of gravitational waves. Inflationary models predict this energy scale as the fourth root of the energy density in the beginning of inflation: the formula is given by in the article of McAllister. This formula contains single dimensionless parameter called r, and BICEP measurements give a rather large value $r = .2$ for it.

The natural expectation is that any theory explaining the findings in terms of gravitons produces similar prediction but with the energy density of scalar field replaced with something else. In TGD the energy density assignable to cosmic strings so that the square root of the energy density of cosmic string multiplied by some numerical factor should be the relevant parameter now.

6.4 Inflation Should Begin At Gut Mass Scale

The first implication of the findings is that if inflation explains the findings, it should have begun in GUT scale 10^{16} GeV, which is very high. The findings cut off a gigantic portion of the parameter space of inflationary models and leaves only inflation potentials that are approximately translationally invariant.

In TGD framework one expects that the energy scale corresponds to that in which quantum critical period begins after string dominated primordial period. This scale should be given by CP_2 mass scale apart from some numerical factor. CP_2 mass corresponds to $m(CP_2) = \hbar/R(CP_2)$, where $R(CP_2)$ is CP_2 radius. p-Adic mass calculations predict the value of electron mass and assign to electron the largest Mersenne prime M_{127} having the property that the p-adic length scales $\sqrt{p}R(CP_2)$ is not completely super-astronomical. This fixes $R(CP_2)$ and $m(CP_2)$. The outcome is $m(CP_2) \sim 5.7 \times 10^{14}$ GeV. One has $m(CP_2)/m_P = .2.4 \times 10^{-4}$.

A numerical constant can be present in the estimate for the energy scale at which quantum critical period begins. In particular, the factor $1/\alpha_K^{1/4}$ should be present since Kähler action is proportional to $1/\alpha_K$, which by simple argument is in excellent approximation equal to the inverse of the fine structure constant equal to 137. This would rise the estimate for the energy scale to about 10^{16} GeV if the same formula for it is used also in TGD (which might of course be wrong!). With a considerable dose of optimism one could say that TGD allows to understand why the measured value of r is what it is.

6.5 Difficulties Of The Inflationary Approach

What is nice that McAllister discusses also so the difficulties of inflationary approach.

1. So called Lyth bound gives lower bound for the distance that inflaton's vacuum expectation must move in field space in order to generate detectably large primordial waves: that is the duration of the inflationary expansion. The lower bound is given by Planck mass M_p: $\Delta\Phi > M_p$.

2. There is however a problem. This distance should be not larger than the cutoff scale Λ of the quantum field theory. But if standard wisdom is taken granted, Λ should be smaller than Planck mass M_p giving $\Delta\Phi < M_p$!

3. One can certainly invent all kinds of tricky mechanisms to circumvent the problem: the proposal considered by McAllister is that the couplings of Φ are suppressed to heavy degrees of freedom so that the UV theory respects the approximate shift symmetry $\Phi \rightarrow \Phi + \Delta\Phi$. This is true for massless scalar field but this field does not develop vacuum expectation value. McAllister mentions that for $V = m^2\Phi^2/2$ the approximate shift symmetry is true. Maybe it is for small enough values of m: exact symmetry would require $m = 0$.

4. The physical interpretation of masslessness implied by strict shift invariance would be in terms of conformal invariance. In TGD framework quantum criticality implies conformal invariance also in 2-D sense and quantum criticality corresponds to the absence of dimensional parameters from Higgs potential making Higgs mechanism impossible.

To my humble opinion, this difficulty means a strong blow against the idea about Higgs mechanism as source of vacuum energy density in cosmology. As already mentioned, the decay of the dark energy identifiable as magnetic energy and large h_{eff} dark matter associated with the evolving primordial cosmic strings would produce ordinary matter in TGD Universe.

Also the ordinary Higgs mechanism is plagued by the loss of naturalness and predictivity by the fact that the Higgs particle has too low mass and SUSY has not been found in low enough mass scales to stabilize Higgs mass. In TGD framework the string tension of string like objects assignable to elementary particles would give the dominating contribution to gauge boson masses and p-adic thermodynamics in its original form the dominating contribution to fermion masses [K13]. The couplings of fermions to Higgs are gradient couplings and the coupling is same for all fermions in accordance with naturality and universality [K24].

6.6 Could TGD Allow Inflationary Cosmology?

A natural question is whether TGD could allow inflationary cosmology. In the lowest order this would require imbedding of the De Sitter space [?]. De Sitter space allows two basic coordinate slicings.

1. The first one corresponds to a stationary metric having interpretation in terms of interior of an object with constant mass density. The line element reads

$$\begin{aligned} ds^2 &= Adt^2 - Bdr^2 - r^2d\omega^2 \ , \\ A &= 1 - (\frac{r}{l})^2 \ , \ B = \frac{1}{A} \ . \end{aligned} \tag{6.1}$$

l has natural interpretation as outer boundary of the object in question. It will be found that TGD suggests 2-fold covering of this metric.

2. Second coordinatization has interpretation as simplest possible inflationary cosmology having flat 3-space:

$$ds^2 = d\hat{t}^2 - e^{2\frac{\hat{t}}{l}}dr^2 - \hat{r}^2d\omega^2 \ . \tag{6.2}$$

3. The two coordinatizations are related to each other by the formulas deducible from the general transformation property of metric tensor:

$$\begin{aligned} t &= \hat{t} + \frac{1}{2}log[1 + (\frac{\hat{r}}{l})^2e^{2\frac{\hat{t}}{l}}] \ , \\ r &= e^{\frac{\hat{t}}{l}}\hat{r} \ . \end{aligned} \tag{6.3}$$

In TGD framework also the imbedding of space-time as surfaces matters besides the metric which is purely internal property. The most general ansatz for the imbedding of De Sitter metric into $M^4 \times CP_2$ is as a vacuum extremal for for Kähler action with the understanding that small deformation carries energy momentum tensor equal to Einstein tensor so that Einstein's equations would old true in statistical sense.

1. The general ansatz for the stationary form of the metric is of same general form as that for Schwartchild metric. One can restrict the consideration to a homologically trivial geodesic sphere S^2 of CP_2 with vanishing induced Kähler form and standard spherical metric. This means that CP_2 is effectively replaced with S^2. This imbedding is a special one but gives a good idea about what is involved.

   Denoting by (m^0, r_M, θ, ϕ) the coordinates of M^4 and by (Θ, Φ) the coordinates of S^2, a rather general ansatz for the imbedding is

$$\begin{aligned} m^0 &= t + h(r) \ , \ r_M = r \ , \\ R\omega \times sin(\Theta(r)) &= \pm\frac{r}{l} \ , \Phi = \omega t + k(r) \ . \end{aligned} \tag{6.4}$$

2. The functions $h(r)$, $k(r)$, and $\Theta(r)$ can be solved from the condition that the induced metric is the stationary metric. For Schwartschild metric $h(r)$ and $k(r)$ are non-vanishing so that the imbedding cannot be said to be stationary at the level of imbedding space since $t = constant$ surfaces correspond to $m_0 - h(r_M) = constant$ surfaces.

   De Sitter metric is however very special. In this case one can assume $h(r) = k(r) = 0$ for $R\omega = 1$. The imbedding reduces simply to an essentially unique imbedding

$$sin(\Theta(r)) = \pm\frac{r}{l} = \frac{r_M}{l} \ , \ \Phi = \frac{t}{R} = \frac{m^0}{R} \ . \tag{6.5}$$

   This imbedding is certainly very natural and would describe stationary non-expanding cosmology with constant mass density. Not that the imbedding is defined only for $r_M < l$. Unless one allows 3-space to have boundary, which for non-vacuum extremals does not seem plausible option, one must assume double covering

$$sin(\Theta(r)) = sin(\pi - \Theta(r)) = \pm\frac{r_M}{l} \ . \tag{6.6}$$

   Stationarity implies that there is no Big Bang.

3. The transition to the inflationary picture looks in TGD framework very much like a trick in which one replaces radial Minkowski coordinate with $\hat{r} = exp(-\hat{t}/l)r_M$ and in these new coordinates obtains Big Bang and exponential expansion as what looks like a coordinate effect at the level of imbedding space. Also the transition to radiation dominated cosmology for which the hyperbolic character of M^4_+ metric $ds^2 = da^2 - a^2(dr^2/(1+r^2) + r^2 d\Omega^2)$ is essential, is difficult to understand in this framework. The transition should correspond to a transition from a stationary cosmology at the level of imbedding space level to genuinely expanding cosmology.

The cautious conclusion is that sub-manifold cosmology neither excludes nor favors inflationary cosmology and that critical cosmology [K19] is more natural in TGD framework. In TGD Universe de Sitter metric looks like an ideal model for the interior of a stationary star characterized by its radius just like blackhole is characterized by its radius. It seems that TGD survives the new findings at qualitative and even partially quantitative level.

6.7 Quantum Critical Cosmology Of TGD Predicts Also Very Fast Expansion

TGD inspired critical cosmology [K19] relies on the identification of 3-space as $a = constant$ section, where a is Lorentz invariant cosmological time defined by the light-cone proper time $a = \sqrt{(m^0)^2 - r_M^2}$, and from the assumption that (quantum) criticality corresponds to a vanishing 3-curvature meaning that 3-space is Euclidian.

The condition that the induced metric of the $a = constant$ section is Euclidian, fixes the critical cosmology apart from its duration a_0 from the existence of its vacuum extremal imbedding to $M^4 \times S^2$, where S^2 homologically trivial geodesic sphere:

$$\begin{aligned} ds^2 &= g_{aa}da^2 - a^2(dr^2 + r^2 d\Omega^2) \ , \\ g_{aa} &= (\frac{dt}{da})^2 = 1 - \frac{\epsilon^2}{1-u^2} \ , \ u = \frac{a}{a_0} \ , \ \epsilon = \frac{R}{a_0} \ . \\ sin(\Theta) &= \pm u \ , \ \Phi = f(r) \ , \\ \frac{1}{1+r^2} &- \epsilon^2(\frac{df}{dr})^2 = 1 \ . \end{aligned} \tag{6.7}$$

From the expression for dt/da one learns that for the small values of a it is essentially constant equal to $dt/da = \sqrt{1-\epsilon^2}$. When a/a_0 approaches to $\sqrt{1-\epsilon^2}$, dt/da approaches to zero so that the rate of expansion becomes infinite. Therefore critical cosmology is analogous to inflationary cosmology with exponential expansion rate. Note that the solution is defined only inside future or past light-cone of M^4 in accordance with zero energy ontology.

After this a transition to Euclidian signature of metric happens (also a transition to radiation dominated cosmology is possible): this is something completely new as compared to the general relativistic model. The expansion begins to slow down now since dt/da approaches infinity at $a/a_0 = 1$. In TGD framework the regions with Euclidian signature of induced metric are good candidates for blackhole like objects. This kind of space-time sheets could however accompany all physical systems in all scales as analogs for the lines of generalized Feynman diagrams. For $sin(\Theta) = 1$ at $a/a_0 = 1$ the imbedding ceases to exist. One could consider gluing together of two copies of this cosmology together with $sin(\Theta) = sin(\pi - \Theta) = a/a_0$ to get a closed space-time surface. The first guess is that the energy momentum tensor for the particles defined by wormhole contacts (see **Fig.** `http://tgdtheory.fi/appfigures/wormholecontact.jpg` or **Fig. ??** in the appendix of this book) connecting the two space-time sheets satisfies Einstein's equations with cosmological constant.

Quantum criticality would be associated with the phase transitions leading to the increase of the length and thickness of magnetic flux tubes carrying Kähler magnetic monopole fluxes and explaining the presence of magnetic fields in all length scales. Kähler magnetic energy density would be reduced in this process, which is analogous to the reduction of vacuum expectation value of the inflation field transforming inflaton vacuum energy to ordinary and dark matter.

At the microscopic level one can consider two phase transitions. These phase transitions are related to the hierarchy of Planck constants and to the hierarchy of p-adic length scales corresponding to p-adic primes near powers of 2.

1. The first phase transition increases Planck constant $h_{eff} = nh$ in a step-wise manner and increases the length and width of the magnetic flux tubes accordingly but conserves the total magnetic energy so that no magnetic energy is dissipated and one has adiabaticity. This sequence of phase transitions would be analogous to slow roll inflation in which the vacuum expectation of inflation field is preserved in good approximation so that vacuum energy is not liberated. The flux tubes contain dark matter.

2. Second phase transition increases the p-adic length scale by a power of $\sqrt{2}$ and increases the length and width of magnetic flux tubes so that the value of the magnetic field is reduced by flux conservation (magnetic flux tubes carry monopole fluxes made possible by CP_2 homology). This phase transition reduces zero point kinetic energy and in the case of magnetic fields magnetic energy transforming to ordinary and dark matter.

3. The latter phase transition can be accompanied by a phase transition reducing Planck constant so that the length of the flux tubes is preserved. In this transition magnetic energy is liberated and dark matter is produced and possibly transformed to ordinary matter. This kind of phase transitions could take place after the inflationary adiabatic expansion and produce ordinary matter. As a matter fact, I have originally proposed this kind of phase transition to be the basic phase transition involved with the metabolism in living matter [K25], which suggests that the creation of ordinary matter from dark magnetic energy could be seen as kind of metabolism in cosmological scales.

   In zero energy ontology one can ask whether one could assign to the Minkowskian and Euclidian periods a sequence of phase transitions increasing Planck constants but proceeding in opposite time directions.

4. During the inflationary period the size scale of the Universe should increase by a factor of order 10^{26} at least. This corresponds to 2^{87} - that is 87 2-foldings, which is a more natural notion than e-folding now. If the size of the sub-Universe is characterized by a p-adic length scale, this would correspond in the final state to $p \sim 2^{174}$ at least: this p-adic length scale is about 4×10^{-5} meters roughly and thus of order cell size.

5. How the transition to radiation dominated cosmology takes place is an interesting question. The decay of the magnetic energy to ordinary matter should take place during the Euclidian period initiating therefore the radiation dominated period. For the radiation dominated cosmology the scale factor behaves as $t \propto a^2$ so that dt/da approaches zero. Since this occurs also when the Euclidian period starts, the guess is that space-time sheets with radiation dominated sub-cosmologies assignable to sub-CDs (CD is shorthand for causal diamond) begin to be created.

Although this picture is only an artist's vision and although one can imagine many alternatives, I have the feeling that the picture might contain the basic seeds of truth.

6.8 Still Comments Abount Inflation In TGD

Quantum criticality is the TGD counterpart of the inflation and the flatness of 3-space follows from the condition that no local dimensional quantities are present in 3-geometry. Also the imbeddability fo M^4 is an important piece of story and restricts the set the parameters of imbeddable cosmologies dramatically.

One can try to understand the situation microscopically in terms of the cosmic strings which gradually develop higher than 2-D M^4 projection during cosmic evolution and become magnetic flux tubes carrying magnetic monopole fluxes explaining the presence of magnetic fields in cosmology.

At microscopic level magnetic flux tubes are the key structural elements. The phase transitions increasing Planck constant for the matter associated with flux tubes and thus also the lengths of magnetic flux tubes should be important as also the phase transitions increasing p-adic prime and reducing Planck constant originally emerged in the modelling of TGD inspired quantum biology are highly suggestive. First transitions would mean adiabatic expansion with no heat generation and latter transitions would liberate magnetic field energy since flux conservation forces field strength to be reduced and leads to liberation of magnetic energy producing ordinary matter and dark matter. Dark energy in turn is identifiable as magnetic energy.

The key question concerns the mechanism causing the isotropy and homogeny of the cosmology. There are two possible identifications.

1. According to two decades old proposal [K19], primordial cosmology before the emergence of space-time sheets could be regarded as string gas in $M^4_+ \times CP_2$ at Hagedorn temperature determined by CP_2 radius: $T_H \sim \hbar/R_{CP_2}$. This phase could be present also after the transition to radiation dominated cosmology and consist of strings, whose thickness is gradually increasing and which contain carry dark energy and dark matter. The horizon radius is infinite for this cosmology thus providing at least partial explanation for the homogeny and isotropy and visible matter would represent deviations from it.

2. The accelerating expansion period towards the end of the critical period could smooth out inhomogenities and thus provide an additional mechanism leading to homogenous and isotropic Big Bang. This for given space-time sheet representing R-W cosmology: in many-sheeted cosmology one can imagine distribution of parameters for the cosmology. The rapid expansion period could however also develop large fluctuations! Indeed, the time $a_F < a_1$ (density would be infinite for a_1) for its end - and therefore local mass density - must have a distribution after the rapid expansion ends. This expansion would generate separate smoothed out radiation dominated space-time sheets with slightly different mass densities and cosmic temperatures. A splitting to smooth radiation dominated sub-cosmologies would take place.

Therefore TGD scenario could be very different from inflationary scenario. The problem is to decide which option is the most feasible one.

The formulas used to make back of the envelope(`http://motls.blogspot.fi/2014/03/inflation-on-back-o html`) calculations in inflation theory discussed in a quest posting in Lubos Motl's blog given some idea about TGD counterpart for the generation of gravitons. Inflationary period is replaced with essentially unique critical cosmology containing only its duration as a free parameter. The fluctuations in the duration of this parameter explain scalar temperature fluctuations assoiated with CMB.

6.8.1 How the local polarization of CMB is generated?

There is a nice discussion about the mechanism leading to the generation of CMB polarization (`http://cosmology.berkeley.edu/~yuki/CMBpol/CMBpol.html`). The polarization is generated after the decoupling of CMB photons from thermal equilibrium and is due to the scattering of photons on free electrons during decoupling. This scattering is known as Thomson scattering. The page in question contains schematic illustrations for how the polarization is generated. The scattering from electrons polarizes the photons in direction orthogonal to the scattering plane. In thermal equilibrium the net polarization of scattered radiation vanishes. If however the scattered photons from two perpendicular directions have different intensities a net polarization develops.

Polarized photons could be produced only during a short period during recombination scattering from free electrons was still possible and photons could diffuse between regions with different temperature. Polarized photons were generated when electrons from hot and cold regions where scattering on same electrons. CMB polarization indeed varies over sky but not in long length scales since photons could not diffuse for long lengths.

So called quadrupole anisotropy of CMB temperature contains information about the polarization. There are `http://background.uchicago.edu/~whu/intermediate/Polarization/ polar4.html`three contributions: scalar, vector, and tensor.

1. Scalar contributions is due to density fluctuations reflecting themselves as temperature fluctuations and does not distinguish between polarizations: this is what has been studied mostly hitherto. A natural TGD mechanism for their generation would be different time for the end of the critical period leading to splitting of critical cosmology to radiation dominated cosmologies with slightly different temperatures.

2. There is also so called vorticity distribution due to the flow which has vorticity and would due to defects/string like objects present also in TGD. The simplified situation corresponds to are region in which one has two flows in opposite direction locally. Depending on whether the scattering photons are upstream or down stream they are blue-shifted or red-shifter so that the temperatures are slightly different in up-stream and down.The flows in opposite direction give rise to a situation in which photons with different temperatures scatter and produce polarization. The effects of vorticity are expected to disappear during the fast expansion period. Probably because the gradients of velocity giving rise to vorticity are smoothed out.

3. The third contribution is tensor contribution and due to gravitons generating stretching and squeezing of space in two orthogonal directions defining polarization tensor. Stretching increases wavelengths and decreases temperature. Squeezing does the opposite. Therefore temperature differences distinguishing between the two directions are generated and the

outcome is polarization of the CMB background much later. This corresponds to the so called E and B modes. One can decompose polarization as vector field to two parts: the first one - the E-mode - is gradient and thus irrotational and second is curl and thus rotational and with vanishing divergence (incompressible liquid flow is a good concrete example).

6.8.2 How the polarization anisotropies could be generated in TGD Universe?

One can try to understand microscopically how the polarization anisotropies are generated in TGD framework using poor man's arguments.

1. One can introduce a vision vision about fractal 3-D network of cosmic strings forming a kinds of grids with nodes in various scales. These grids would be associated with different levels of the hierarchy of space-time sheets associated with many-sheeted space-time. Coordinate grid is of course an idealization since three coordinate lines would meet in single node. A weaker form of grid would involve meeting of two coordinate lines at given node. There is data about our own galactic nucleus understood if it correspond to the node at which two magnetic flux tubes meet. Ordinary visible matter would be generated in nodes. One might say that galaxies are due to traffic accidents in which dark matter arriving along two cosmic strings collides in the crossing of the roads. Flux tubes would be attracted together by gravitational attraction so from the crossing.

2. Amusingly, the notion grid emerged also TGD inspired quantum biology as a proposal for how living system codes morphogenetic position information. Flux tubes carry dark matter and ordinary matter is associated with the nodes at which coordinate lines meet each other. This web can give rise to a generalization of topological quantum computation using 2-braids. Coordinate lines define strings which can be knotted in 3-dimensions and define braids making possible topological quantum computation using macroscopic quantum phases defined by the dark matter. The time evolutions of coordinate lines defines string world sheets and in 4-D space-time the string world sheets can be knotted and braided so that also higher level TQC becomes possible with string reconnection and going above or below the other define two bits in each node.

3. The presence of grid could also explain the honeycomb like structure of Universe with the recent typical size of honeycomb about 10^8 ly.

4. In this framework the illustrations for how the gravitational waves induce the polarization of CMB. The radiation beams entering from opposite directions can be assigned with two magnetic flux tubes meeting at the node and in slightly different temperatures due to the interaction with gravitons much earlier. The gravitons can be regarded as larger space-time sheets at which the two flux tubes had contacts so that space associated with the flux tubes was forced to stretch or squeeze. This in turn increased of reduced photon wavelength so that photon temperature at flux tubes was different and the difference were preserved during subsequent evolution.

6.8.3 Back on the envelope calculations in TGD framework

One can modify the back on the envelope calculations of John Preskill (`http://motls.blogspot.fi/2014/03/inflation-on-back-of-envelope`.html) in Lubos Motl's blog to see what could happen in TGD framework. Now one however starts from the critical cosmology fixed apart from its duration and looks what it gives rather than starting from Higgs potential for inflaton field. The obvious counterpart for inflaton scalar field would be magnetic field intensity having same dimension but one should avoid too concrete correspondences.

The key question is whether the critical period generates the rapid expansion smoothing out inhomogenities or whether it generates them. The original guess that it smooths them out turns out be wrong in closer examination.

1. The basic equation in inflationary model is given by

$$(\frac{\dot{a}}{a)})^2 = \frac{V}{m_p^2}$$

If V is small this has as solution $a(t) = a(0)exp(Ht)$ if $G = \sqrt{V}/m_p$ is constant. De Sitter cosmology allows partial imbedding in TGD but the imbedding is naturally static and has interpretation as black-hole interior with constant mass density. One can find coordinates in which the solution looks like expanding cosmology without Big Bang but these coordinates are not natural from the view of imbedding space.

2. In TGD the expression for $\dot{a}$ for critical cosmology is

$$\dot{a} = \sqrt{\frac{a_0^2 - a^2}{a_0 2^- R^2 - a^2}} \ .$$

a_0 is roughly the duration of cosmology and R is CP_2 radius of order $10^{3.5}$ Planck lengths. The almost uniqueness follows from the condition that the imbedding is such that the induced metric at the 3-surfaces defined by intersections with hyperboloids of M^4_+ is flat rather than hyperbolic. This cosmology differs from de-Sitter cosmology.

3. For $a \rightarrow 0$ one has

$$\dot{a} \simeq \frac{a_0^2}{a_0^2 - R^2} \simeq 1 \ .$$

so that one has $\dot{a} \simeq 1$ and $a \simeq t$ for small values of a in accordance with the replacement of Big Bang with a "silent whisper amplified to a Big Bang" (density of matter goes as $1/a^2$) Hubble constant goes like $H \propto 1/a$ so that Hubble radius divergence. This does not guarantee that horizon radius becomes infinite. Rather, the horizon is finite and given in good accuracy by the duration $a_1 = \sqrt{a_0^2 - R^2}$ of the period. One can however explain the isotropy and homogenity of the string gas in M^4_+ carrying flux tubes carrying dark matter and energy in terms of the infinite horizon of M^4.

There is no exponential time evolution at this period since one has $a \simeq t$ in good approximation for $a/a_0 << 1$. The TGD counterpart of V would behave like $1/a^2$ which conforms with the idea that V corresponds to energy density.

4. As the limit $a \rightarrow a_1 = \sqrt{a_0^2 - R^2}$ is approached, the expansion rate approaches infinite and for $a > a_1$ at the latest one expects radiation dominated cosmology: otherwise a region of Euclidian signature of the induced metric results. The expectation is that a transition to radiation dominated cosmology takes place before $a = a_1$ at which also energy density would diverge. The question is whether this period means smoothing out of inhomogenities or generation of them or both.

Consider now what could happen near the end of the Minkowskian period of critical cosmology.

1. Although it is not clear whether rapidly accelerating expansion is needed to to smooth out homogenities, one can just find what conditions this would give on the parameters. For $a_i = kR$ at which phase transition began the condition that a was increased at least by factor $e^{50} \sim 5 \times 10^{21}$ (50 e-folds) this would give $a_1 \simeq a_0 > e^{50}kR$. For $k \sim 1$ this gives something like 10^{-18} seconds, which happens to correspond atomic length scale. Below it will be found that this period more naturally corresponds to the period during which large fluctuations in density distribution and metric are generated.

2. The earlier estimate for the emergence of radiation dominated cosmology discussed in [K19] assumed that the transition to radiation dominated cosmology takes place at CP_2 temperature defining Hagedorn temperature at which temperature of the string gas cannot be raised anymore since all the energy goes to the generation of string excitations rather than to kinetic energy, gives $a_F \sim 10^{-10}$ seconds, which is by factor 10^8 larger. If this were true, the fast expansion period a_F would increase the scale factor to about 68 e-folds equivalent to 98 2-folds. p-Adic prime $p \simeq 2^{196}$ would correspond to p-adic length scale about $L(196) \sim .1$ meters. The crucial assumption would be that the the time a_f at which the expansion ends is same everywhere. There is no reason to assume this and this would mean that the period

in question generates inhomogenities and isotropies of mass distribution and temperature distribution.

Note that if the distribution of the time $a_F < a_1$ at which the critical period ends is responsible for the CMB fluxtuations then the number of foldings characterizes the smoothness of given local radiation dominated cosmology and could be rather large.

3. The rapid accelerating expansion occurs as g_{aa} approaches zero. Indeed, for

$$a \to a_1 = \sqrt{a_0^2 - R^2}$$

a very rapid expansion occurs and $\dot{a}$ approaches infinite value. Near to a_1 one can write $a/a_1 = 1 - \delta$ and solve δ approximately as function of t as

$$\delta = (\frac{3R^2}{4a_1^2})^{2/3}(\frac{t-t_1}{a_1})^{2/3} \quad , \quad t_1 = \int_0^{a_1} \frac{(1-\frac{a^2}{a_1^2})^{1/2}}{(1-\frac{a^2}{a_1^2})^{1/2}} \quad .$$

Hubble constant behaves as

$$H \equiv \frac{\dot{a}}{a} = \frac{R^2}{2a_1^3}\delta^{-1/2} \quad .$$

4. What is interesting is that applying the naive dimensional estimate for the amplitude of gravitational fluctuations to be $\delta h_T^2 \sim H^2/m_P^4$. This would mean that at the limit $a \to a_F < a_1$ gravitational fluctuations become very strong and generate the strong graviton background. Same applies to fluctuations in mass density.

6.8.4 Summary

The possibility of very rapid expansion near $a = a_F < a_1$ leading to radiation dominated cosmology should have some deep meaning. The following tries to catch this meaning.

1. The explosive period could lead to a radiation dominated cosmologies from string dominated cosmology with Hagedorn temperature. It could involve h_{eff} increasing phase transitions for string gas during the initial period and liberation of magnetic energy during the end period as massless particles: this would explain why the mass density of the space-time sheet increases dramatically. The critical cosmology could correspond to a phase transition from a phase with Hagedorn temperature identified as $T_H \propto \hbar/R_H$ to radiation dominated cosmology.

2. The cooling of string gas would lead to the generation of hierarchy of Planck constants and liberation of the magnetic energy of strings as massless particles during the end of critical period topologically condensing to space-time sheets such as massless extremals. This process could correspond to the rapid increase of energy density towards the end of the critical period.

3. Isotropy and homogenity appear both at the level of imbedding space and space-time sheets. The infinite horizon of M^4_+ would explain the isotropy and homogenity of string gas in H both before and after the emergence of space-time sheets at Hagedorn temperature around $a \sim R_{CP_2}$. In particular, the smoothness of the cosmology of dark matter and dark energy would find explanation. The rapid expansion would in turn smooth out inhomogenities of individual space-time sheets.

4. The Hubble scale $1/H$ approaches to zero as $a = a_F < a_1$ is approached. The rapid expansion destroys anisotropies and inhomogenities of radiation dominated space-time sheet corresponding to particular value of a_F. The distribution for values of a_F in turn explains CMB scalar fluctuations since the energy density in final state is highly sensitive to the precise value of a_F. This distribution would be Gaussian in the first approximation. One can say that the fluctuation spectrum for inflaton field is replaced with that for a_F.

5. Also the generation of gravitational radiation and its decoupling from matter could take place during the same end period. After this gravitational fields would be essentially classical and assignable to space-time sheets. Essentially formation of gravitationally bound states would be in question analogous to what happens photons decouple from matter much later. The reduction of the temperature of string gas below Hagedorn temperature could generate also the massless graviton phase decoupling from matter and inducing the temperature fluctuations and polarization during decoupling.

   Gravitons and also other particles would topological condense at "massless extremals" (MEs, topological light rays) and particles - in particular photons - would interact with gravitons by generating wormhole contacts to gravitonic MEs. The interaction between MEs assignable to gravitational radiation and photons would have caused the fluctuations of CMB temperature.

To sum up, if the TGD inspired picture is correct then Penrose (http://www.sciencefriday.com/segment/04/04/2014/sir-roger-penrose-cosmic-inflation-is-fantasy.html) would have been correct in the identification of string theory as fashion and inflationary cosmology as fantasy (for the strong reaction of Lubos Motl see http://motls.blogspot.fi/2014/04/roger-penrose-continues-his-weird-anti.html). Also the fact that inflationary cosmology is at the verge of internal contradiction due the fact that the assumption of field theoretic description is in conflict with the large graviton background suggests that inflationary cosmology is not for long with us anymore.

6.9 Could The Polarization Be Due To The Dark Synchrotron Radiation?

I have commented in several postings (http://matpitka.blogspot.fi/2014/03/bicep2-might-have-detected.html, http://matpitka.blogspot.fi/2014/03/could-tgd-allow-inflationary-cosmology.html, http://matpitka.blogspot.fi/2014/03/quantum-critical-cosmology-of-tgd.html, and http://matpitka.blogspot.fi/2014/04/still-about-tgd-and-inflation.html) the BICEP claim of having detected primordial B-modes in the polarization of cosmic microwave background (CMB). The claim was that effect was produced by the interaction of microwave photons from the effects caused by primordial gravitons on the space-time geometry caused by the presence of the gravitons. The effect was unexpectedly large and challenges quantum field theoretic description used in inflation paradigm: note that inflation paradigm postulates the existence of Higgs like particle called inflaton.

Now Jester (http://resonaances.blogspot.fi/2014/05/is-bicep-wrong.html) tells in his blog that there are rumours that BICEP2 group might have underestimated the effect of galactic foreground. There is also a little article in Science Now about the situation (http://news.sciencemag.org/physics/2014/05/blockbuster-big-bang-result-may-fizzle-rumor-suggests).

BICEP signal is taken only at single frequency: 150 GHz. Planck has published a polarization at 353 GHz demonstrating that there may be a significant foreground emission from the galactic dust in the parts of sky studied by BICEP. The Planck collaboration has masked the results in BICEP patch: this does not certainly help BICEP team in their work. It is a pity that competition between research groups leads to this kind of secrecy.

Whether or not the BICEP finding is correct does not affect much neither inflationary models or TGD model. In inflationary approach there are so many variants to consider that one can always find candidate models. The reduction of B-mode contribution would be actually well-come since it would allow to get rid of the internal consistency problem. In TGD framework there is also rapid accelerating expansion analogous to that of inflationary expansion but the no inflatons are needed. Quantum criticality implies vanishing 3-curvature and this fixes the cosmology apart from the duration of the critical phase. The model is not quantum field theoretic anymore: gas of cosmic strings inside Minkowski space light-cone prevails before the inflationary period which is critical period for the phase transition to a radiation dominated cosmology. The problem is that one (more precisely, I) cannot really calculate precise prediction for the size of the effect.

The B-mode contribution should be disentangled from two foreground contributions from synchrotron radiation and galactic dust. The problems with BICEP are possibly related to the latter one. I cannot of course say anything interesting about the experimental side of the problem.

One can however ask TGD might predict new kind of synchrotron contribution. In TGD Universe magnetic flux tubes in various scales are basic objects and essential also in the model for temperature fluctuations and polarization of CMB resulting from slightly different temperatures for the two polarization of CMB. The magnetic flux tubes carry monopole fluxes making their existence possible without currents generating then. Their magnetic energy can be identified as dark energy. They carry also dark variants of ordinary particles identified as phases with Planck constant coming as integer multiple of the ordinary one. Could the charged particles - in particular electrons - rotating at cyclotron orbits at these flux tubes produce cyclotron radiation at CMB frequencies and thus giving rise to its apparent polarization?

Concerning cyclotron radiation one can consider relativistic/non-relativistic and classical/quantal situations.

1. In Wikipedia there is article about classical model for cyclotron radiation (`http://en.wikipedia.org/wiki/Synchrotron_radiation`). One expects that the qualitative aspects remain the same in quantal treatment. For planar motion around magnetic field the radiation has dipole pattern around the axis of motion in non-relativistic situation. In relativistic situation it is strongly peaked around the direction of motion at frequency of order γ^3/ρ where γ is the relativistic time dilation factor and ρ is the radius of the orbit which gradually decreases. Most of the radiation is in the plane orthogonal to the orbit and the polarization in the plane of the orbit is parallel to the plane and orthogonal to the line of sight.

2. Quantum model might be relevant if the charged particles are in large h_{eff} phase at magnetic flux tubes and emit dark photons with scaled up energies. Dark photons would later transform to bunches of ordinary photons and if their energies are in the region corresponding to CMB they might produces additional contribution.

   In quantum case the charged particles behaves like a 2-D harmonic oscillator in degrees of freedom orthogonal to the magnetic field and energy is quantized as multiples of the cyclotron energy $E = n \times h_{eff}\omega$, $\omega = ZeB/m$. Note the upwards scaling of energy by h_{eff}. The frequencies of the emitted radiation come a multiples of the cyclotron frequency and can be rather high. The Bohr radii of the orbits are quantized and the spiral orbit with decreasing radius is replaced with a sequence of circular orbits with instantaneous jumps to orbit with smaller radius. One expects that the general polarization characteristics are same as in the classical case and that classical description is a good approximation also now.

Could this kind of dark radiation give an apparent contribution to CMB? The following very naive scaling estimate is an attempt to answer the question.

1. The local direction of the vector field defined by the local polarization of CMB photons should be equal to the local direction of magnetic flux tubes in question so that the polarization map would give a map of flux tubes carrying dark matter. This would be of course extremely nice.

2. The condition that the radiation is in CMB range implies that the frequency is of order 100 GHz. Electron or electron Cooper is the best candidate for the dark charged particle in question. The cyclotron frequency of electron is $f = 6 \times 10^5$ Hz in the magnetic field of.2 Gauss (familiar to me from TGD inspired quantum biology!). From this one deduces that a magnetic fields in question should be in Tesla range if they are to affect the CMB background.

3. If one requires quantization of the flux then minimal flux quantum for ordinary value of Planck constant would have a minimal thickness of order $R = 10$ nm. By naive scaling the flux quantum is proportional to h_{eff} so that by a naive scaling the minimal radius of flux tube would scale like $h_{eff}^{1/2}$ and be thus larger than 10 nm lower bound.

   Macroscopic situation would correspond to very large thickness scaling as $n^{1/2}$, where integer n characterizes the quantized flux. Macroscopic effective thickness is of course required by data. Very large values of h_{eff} or n would be required to give realistic values for the flux tube radius. In the fractal Universe of TGD a fractal hierarchy of flux tubes within flux tubes picture is expected and one could have bunches of flux tubes with thickness $h_{eff}^{1/2} \times R$.

I leave it for the reader to guess whether this contribution could mimic the CMB polarization detected by BICEP.

7 Cyclic cosmology from TGD perspective

The motivation for this piece of text came from a very inspiring interview of Neil Turk by Paul Kennedy in CBS radio (see `http://tinyurl.com/hzw8k68`). The themes were the extreme complexity of theories in contrast to exrteme simplicity of physics, the mysterious homegeny and isotropy of cosmology, and the cyclic model of cosmology developed also by Turok himself. In the following I will consider these issues from TGD viewpoint.

7.1 Extreme complexity of theories *viz* extreme simplicity of physics

The theme was the incredible simplicity of physics in short and long scales *viz.* equally incredible complexity of the fashionable theories not even able to predict anything testable. More precisely, super string theory makes predictions: the prediction is that every imaginable option is possible. Very safe but not very interesting. The outcome is the multiverse paradigm having its roots in inflationary scenario and stating that our local Universe is just one particular randomly selected Universe in a collection of infinite number of Universes. If so then physics has reached its end.

This unavoidably brings to my mind the saying of Einstein: "Any intelligent fool can make things bigger, more complex, and more violent. It takes a touch of genius and a lot of courage to move in the opposite direction.".

Turok is not so pessimistic and thinks that some deep principle has remained undiscovered. Turok's basic objection against multiverse is that there is not a slightest thread of experimental evidence for it. In fact, I think that we can sigh for relief now: multiverse is disappearing to the sands of time, and can be seen as the last desperate attempt to establish super string theory as a respectable physical theory.

Emphasis is now in the applications of AdS/CFT correspondence to other branches of physics such as condensed matter physics and quantum computation. The attempt is to reduce the complex strongly interaction dynamics of conformally invariant systems to gravitational interaction in higher dimensional space-time called bulk. Unfortunately this approach involves the effective field theory thinking, which led to the landscape catastrophe in superstring theory. Einstein's theory is assumed to describe low energy gravitation in AdS so that higher dimensional blackholes emerge and their interiors can be populated with all kinds of weird entities. For TGD view about the situation see [K26].

One can of course criticize Turok's view about the simplicity of the Universe. What we know that *visible* matter becomes simple both at short and long scales: we actually know very little about dark matter. Turok also mentions that in our scales - roughly the geometric mean of shortest and longest scales for the known Universe - resides biology, which is extremely complex. In TGD Universe this would due to the fact that dark matter is the boss for living systems and the complexity of visible matter reflects that of dark matter. It could be that dark matter levels corresponding to increasing values of h_{eff}/h get increasingly complex in long scales and complexity increases. We just do not see it!

7.2 Why the cosmology is so homogenous and isotropic?

Turok sees as one of the deepest problems of cosmology the extreme homogeny and isotropy of cosmic microwave background implying that two regions with no information exchange have been at the same temperature in the remote past. Classically this is extremely implausible and in GRT framework there is no obvious reason for this. Inflationary scenario is one possible mechanism explaining this: the observed Universe would have been very small region, which expanded during inflationary period and all temperature gradients where smoothed out. This paradigm has several shortcomings and there exists no generally accepted variant of this scenario.

In TGD framework one can also consider several explanations.

1. One of my original arguments for $H = M^4 \times CP_2$ was that the imbeddability of the cosmology to H forces long range correlations [K7, K19, K27]. The theory is Lorentz invariant and

standard cosmologies can be imbedded inside future light-cone with its boundary representing Big Bang. Only Roberton-Walker cosmologies with sub-critical or critical mass are allowed by TGD. They are Lorentz invariant and therefore a very natural option [K19]. One would have automatically constant temperature. Could the enormous reduction of degrees of freedom due to the 4-surface property force the long range correlations? Probably not. 4-surface property is a necessary condition but very probably far from enough.

2. The primordial TGD inspired cosmology is cosmic string dominated: one has a gas of string like objects, which in the ideal case are of form $X^2 \times Y^2 \subset M^4 \times CP_2$, where X^2 is minimal surface and Y^2 complex surface of CP_2. The strings can be arbitrarily long unlike in GUTs. The conventional space-time as a surface representing the graph of some map $M^4 \to CP_2$ does not exist during this period. The density goes like $1/a^2$, a light-cone proper time, and the mass of co-moving volume vanishes at the limit of Big Bang, which actually is reduced to "Silent Whisper" amplified later to Big Bang.

   Cosmic string dominated period is followed by a quantum critical period analogous to inflationary period as cosmic strings start to topologically condense at space-time sheets becoming magnetic flux tubes with gradually thickening M^4 projections. Ordinary space-time is formed: the critical cosmology is universal and uniquely fixed apart from single parameter determining the duration of this period.

   After that a phase transition to the radiation dominated phase takes place and ordinary matter emerges in the decay of magnetic energy of cosmic strings to particles - Kähler magnetic energy corresponds to the vacuum energy of inflaton field. This period would do analogous to inflationary period. Negative pressure would be due to the magnetic tension of the flux tubes.

   Also the asymptotic cosmology is string dominated since the corresponding density of energy goes like $1/a^2$ as for primordial phase whereas for matter dominated cosmology it goes like $1/a^3$. This brings in mind the ekpyrotic phase of the cyclic cosmology.

3. This picture is perhaps over-simplified. Quite recently I proposed a lift of Kähler action to its 6-D twistorial counterpart [K28]. The prediction is that a volume term with positive coefficient representing cosmological constant emerges from the 6-D twistorial variant of Kähler action via dimensional reduction. It is associated with the S^2 fiber of M^4 twistor space and Planck length characterizes the radius of S^2. Volume density and magnetic energy density together could give rise to cosmological constant behind negative pressure term. Note that cosmological term for cosmic strings reduces to similar form as that from Kähler action and depending on the value of cosmological constant only either of them or both are important. TGD suggest strongly that cosmological constant Λ has a spectrum determined by quantum criticality and is proportional to the inverse of p-adic length scale squared so that both terms could be important. If cosmological constant term is small always the original explanation for the negative pressure applies.

   The vision about quantum criticality of TGD Universe would suggest that the two terms has similar sizes. For cosmic strings the cosmological term does not give pressure term since it come from the string world sheet alone. Thus for cosmic strings Kähler action would define the negative pressure and for space-time sheets both. If the contributions could have opposite signs, the acceleration of cosmic expansion would be determined by competing control variables. To my best understanding the signs of the two contributions are same (my best understanding does snot however guarantee much since I am a numerical idiot and blundering with numerical factors and signs are my specialities). If the signs are opposite, one cannot avoid the question whether quantum critical Universe could be able to control its expansion by cosmic homeostasis by varying the two cosmological constants. Otherwise the control of the difference of accelerations for expansion rates of cosmic strings and space-time sheets would be possible.

4. A third argument explaining the mysterious temperature correlations relies on the hierarchy of Planck constants $h_{eff}/h = n$ labelling the levels of dark matter hierarchy with quantum scales proportional to n. Arbitrary large scales would be present and their presence would imply a hierarchy of arbitrary large space-time sheets with size characterized by n. The

dynamics in given scale would be homogenous and isotropic below the scale of this space-time sheet.

One could see the correlations of cosmic temperature as a signature of quantum coherence in cosmological scales involving also entanglement is cosmic scales [K26]. Kähler magnetic flux tubes carrying monopole flux requiring no currents to generate the magnetic fields inside them would serve as correlates for the entanglement just as the wormholes serve as a correlate of entanglement in ER-EPR correlations. This would conform with the fact that the analog of inflationary phase preserves the flux tube network formed from cosmic strings. It would also explain the mysterious existence of magnetic fields in all scales.

7.3 The TGD analog of cyclic cosmology

Turok is a proponent of cyclic cosmology [E24, E29, E9] (see `http://tinyurl.com/hrlzdkp`) combining so called ekpyrotic cosmology and inflationary cosmology. This cosmology offers a further solution candidate for the homogeny/isotropy mystery. Contracting phase would differ from the expanding phase in that contraction would be much slower than expansion and only during the last state there would be a symmetry between the two half-periods. In concrete realizations inflaton type field is introduced. Also scenarios in which branes near each other collide with each other cyclically and generate in this manner big crunch followed by big bang is considered. I find difficult to see this picture as a solution of the homogeny/isotropy problem.

I however realized it is possible to imagine a TGD analog of cyclic cosmology in Zero Energy Ontology (ZEO). There is no need to assume that this picture solves the homogeny/isotropy problem and cyclicity would correspond to kind of biological cyclicity or rather sequence of re-incarnations in the sense of TGD inspired theory of consciousness.

1. In ZEO the basic geometric object is causal diamond (CD), whose M^4 projection represents expanding spherical light-front, which at some moment begis to contract - this defines an intersection of future and past directed light-cones. Zero energy states are pairs of positive and negative energy states at opposite light-like boundaries of CD such that all conserved quantum numbers are opposite. This makes it possible to satisfy conservation laws. ZEO, in particular CDs, are forced by the finiteness of the dimensionally reduced 6-D Kähler action for the twistor lift of space-time containing also volume term diverging for infinitely large space-time surfaces.

2. CD is identified as 4-D perceptive field of a conscious entity in the sense that the contents of conscious experiences are from CD. Does CD is represent only the perceptive field of an observer getting sensory representation about much larger space-time surface continuing beyond the boundaries of CD or does the geometry of CD imply cosmology, which is Big Bang followed by a Big Crunch. Or do the two boundaries of CD define also space-time boundaries so that space-time would end there.

   The conscious entity defined by CD cannot tell whether this is the case. Could a larger CD containing it perhaps answer the question? No! For larger CD the CD could represent the analog of quantum fluctuation so that space-time of CD would not extend beyond CD.

3. The geometry of CD brings in mind Big Bang - Big Crunch cosmology. Could this be forced by boundary conditions at future and past boundaries of CD meeting along the large 3-sphere forcing Big Bang at both ends of CD but in opposite directions. If CD is independent geometric entity, one could see it as Big Bang followed by Big Crunch in some sense but not in a return back to the primordial state: this would be boring and in conflict with TGD view about cosmic evolution.

4. To proceed some TGD inspired theory of consciousness is needed. In ZEO quantum measurement theory extends to a theory of consciousness. State function reductions can occur to either boundary of CD and Negentropy Maximization Principle (NMP) dictates the dynamics of consciousness [K15].

   Zeno effect generalizes to a sequence of state function reductions leaving second boundary of CD and the members of zero energy states at it unchanged but changing the states at opposite boundary and also the location of CD so that the distance between the tips of CD is increasing reduction by reduction. This gives rise to the experienced flow of subjective time and its correlation with the flow of geometric time identified as the increase of this distance.

The first reduction to opposite boundary is forced to eventually occur by NMP and corresponds to state function reduction in the usual sense. It means the death of the conscious entity and its re-incarnation at opposite boundary, which begins to shift towards opposite time direction reduction by reduction. Therefore the distance between the tips of CD continues to increase. The two lifes of self are lived in opposite time directions.

5. Could one test this picture? By fractality CDs appear in all scales and are relevant also for living matter and consciousness. For instance, mental images should have CDs as correlates in some scale. Can one identify some analogy for the Big Bang-Big Crunch cosmology for them? I have indeed considered what time reversal for mental images could mean and some individuals (including me) have experienced it concretely in some altered states of consciousness.

The question that I am ready to pose is easy to guess by a smart reader. Could this sequence of life cycles of self with opposite directions of time serve as TGD analog for cyclic cosmology?

1. If so, the Universe could be seen a gigantic organism dying and re-incarnating and quantum coherence even in largest scales would explain the long range correlations of temperature in terms of entanglement - in fact negentropic entanglement, which is basic new element of TGD based generalization of quantum theory.

2. Big Crunch to primordial cosmology destroying all achievements of evolution should not occur at any level of dark matter hierarchy. Rather the process leading to biological death would involve the deaths of various subsystems with increasing scale and eventually the death in the largest scale involved.

3. The system would continue its expansion and evolution from the state that it reached during the previous cycle but in opposite time direction. What would remain from previous life would be the negentropic entanglement at the evolving boundary fixed by the first reduction to the opposite boundary, and this conscious information would correspond to static permanent part of self for the new conscious entity, whose sensory input would come from the opposite boundary of CD after the re-incarnation. Birth of organism should be analogous to Big Bang - certainly the growth of organism is something like this in metaphoral sense. Is the decay of organism analogous to Big Crunch?

4. What is remarkable that both primordial and asymptotic cosmology are dominated by string like objects, only their scales are different. Therefore the primordial cosmology would be dominated by cosmic strings thickened to cosmic strings also for the reversed cycle. Even more, the accelerated expansion could rip the space-time - this is one of the crazy looking predictions of accelerating expansion - and one would have free albeit thickened cosmic strings. In rough enough resolution they would look like ideal cosmic strings.

The re-cycling would not be trivial and boring (dare I say stupid) repeated return to the same primordial state in conflict with NMP implying endless evolution. It would involve scaling up at each rebirth. The evolution would be like a repeated zooming up of Mandelbrot fractal! Breathing is a good metaphor for this endless process of re-creation: God is breathing! Or Gods, since the is fractal hierarchy of CDs within CDs.

5. There is however a trivial problem that I did not first notice. The light-cone proper times $a_\pm$ assignable to the two light-cones $M^4_\pm$ defining CD are not same. If future directed light-cone M^4_+ corresponds to $a_+^2 = t^2 - r_M^2$ with the lower tip of CD at $(t, r_M) = (0, 0)$, the light-cone proper time associated with M^4_- corresponds $a_-^2 = (t-T)^2 - r_M^2 = a_+^2 - 2tT + T^2 = a_+^2 - 2\sqrt{a_+^2 + r_M^2}T + T^2$. The energy density would behave near the upper tip like $\rho \propto 1/a_+^2$ rather than $\rho \propto 1/a_-^2$. Does this require that a Big Crunch occurs and leads to the phase where one has gas of cosmic strings in M^4_-? This does not seem plausible. Rather, the gas of presumably thickened cosmic strings in M^4_- is generated in the state function reduction

to the opposite boundary. This state function reduction would be very much like the end of world and creation of a new Universe.

To sum up, single observation - the constancy of cosmic temperature - gives strong support for extremely non-trivial and apparently completely crazy conclusion that quantum coherence is present in cosmological scales and also that Universe is living organism. This should prove how incredibly important the interaction between experiment and theory is.

8 Is inflation theory simply wrong?

I listened a very nice (see `http://vms.fnal.gov/asset/detail?recid=1944338`) about inflation by Steinhardt, who was one of the founders of inflation theory and certainly knows what he talks. Steinhardt concludes that inflation is simply wrong. He discusses three kind of flexibilities of inflationary theory, which destroy its ability to predict and makes it non-falsifiable and therefore pseudoscience.

Basically cosmologists want to understand the extreme simplicity of cosmology. Also particle physics has turned to be extremely simple whereas theories have during last 4 decades become so complex that they cannot predict anything.

1. CMB temperature is essentially constant. This looks like a miracle. The constant cosmic temperature is simply impossible due to the finite horizon size in typical cosmology making impossible classical communications between distant points so that temperature equalization cannot take place.

2. One must also understand the almost flatness of 3-space: the value of curvature scalar is very near to zero.

Inflation theories were proposed as a solution of these problems.

The great vision of inflationists is that these features of the universe result during an exponentially fast expansion of cosmos - inflationary period - analogous to super-cooling. This expansion would smooth out all inhomogenities and an-isotropies of quantum fluctuation and yield almost flat universe with almost constant temperature with relative fluctuations of temperature of order 10^{-5}.

The key ingredient of recent inflation theories is a scalar field known as inflaton field (actually several of them are needed). There are many variants of inflationary theory (see `https://ned.ipac.caltech.edu/level5/Watson/Watson5_3.html`).

Inflaton models are characterized by the potential function $V(\Phi)$ of the inflaton field Φ analogous to potential function used in classical mechanics. During the fast expansion $V(\Phi)$ would vary very slowly as a function of the vacuum expectation value of Φ . Super cooling would mean that Φ does not decay to particles during the expansion period.

1. In "old inflation" model cosmos was trapped in a false minimum of energy during expansion and by quantum tunneling ended up to true minimum. The liberated energy decayed to particles and reheated the Universe. No inflaton field was introduced yet. This approach however led to difficulties.

2. In "new inflation" model the effective potential $V_{eff}(\Phi, T)$ of inflaton field depending on temperature was introduced. It would have no minimum above critical temperature and super-cooling cosmos would roll down the potential hill with a very small slope. At critical temperature the potential would change qualitatively: a minimum would emerge at critical temperature and the inflaton field fall to the minimum and decay to particles and causes reheating. This is highly analogous to Higgs mechanism emerging as the temperature reduces below that defined by electroweak mass scale.

3. In "chaotic inflation" model there is no phase transition and the inflaton field rolls down to true vacuum, where it couples to other matter fields and decays to particles. Here it is essential that the expansion slows down so that particles have time to transform to ordinary particles. Universe is reheated.

8.1 Objections of Steinhardt against inflation

Consider now the objections of Steinhardt against inflation. As non-specialist I can of course only repeat the arguments of Steinhardt, which I believe are on very strong basis.

1. The parameters characterizing the scalar potential of inflaton field(s) can be chosen freely. This gives infinite flexibility. In fact, most outcomes based on classical inflation do not predict flat 3-space in recent cosmology! The simplest one-parameter models are excluded empirically. The inflaton potential energy must be very slowly decreasing function of Φ: in other words, the slope of the hill along which the field rolls down is extremely small. This looks rather artificial and suggests that the description based on scalar field could be wrong.

2. The original idea that inflation leads from almost any initial conditions to flat universe, has turned out to be wrong. Most initial conditions lead to something very different from flat 3-space: another infinite flexibility destroying predictivity. To obtain a flat 3-space must assume that 3-space was essentially flat from beginning!

3. In the original scenario the quantum fluctuations of inflaton fields were assumed to be present only during the primordial period and single quantum fluctuation expanded to the observer Universe. It has however turned out that this assumption fails for practically all inflationary models. The small quantum fluctuations of the inflationary field still present are amplified by gravitational backreaction. Inflation would continue eternally and produce all possible universes. Again predictivity would be completely lost. Multiverse has been sold as a totally new view about science in which one gives up the criterion of falsifiability.

Steinhardt discusses Popper's philosophy of science centered around the notions of provability, falsifiability, and pseudoscience. Popper state that in natural sciences it is only possible to prove that theory is wrong. A toy theory begins with a bold postulate "All swans are white!". It is not possible to prove this statement scientifically because it should be done for all values of time and everywhere. One can only demonstrate that the postulate is wrong.

Soon one indeed discovers that there are also some black swans. The postulate weakens to "All swans are white except the black ones!". As further observations accumulate, one eventually ends up with not so bold postulate "All swans have some color.". This statement does not predict anything and is a tautology. Just this has happened in the case of inflationary theories and also in the case of superstring theory.

Steinhardt discusses the "There is no viable alternative" defense, which also M-theorists have used. According to Steinhardt there are viable alternatives and Steinhardt discusses some of them. The often heard excuse is also that superstring theory is completely exceptional theory because of its unforeseen mathematical beauty: for this reason one should give up the falsifiability requirement. Many physicists, including me, however are unable to experience this heavenly beauty of super strings: what I experience is the disgusting ugliness of the stringy landscape and multiverse.

8.2 The counterpart of inflation in TGD Universe and twistor lift of Kähler action

The TGD variant of very early cosmology [K19] differs considerably from inflationary scenario but has also some common features.

The basic challenges are following.

1. One should understand the constancy of CMB temperature.

   Hint: String dominated cosmology with matter density behaving like $1/a^2$, a light-cone proper time defining the scaling factor of 3-D part of Friedman metric. This makes classical communications over infinitely long ranges possible and equalization of the temperature. At the moment of big-bang - second boundary of causal diamond (CD), which is part of boundary of light-cone - the distance between points in light-like radial direction vanishes. This could be the geometric correlate for the possibility of communications and long range quantum entanglement.

2. One should understand the flatness of 3-space.

   Hint: (Quantum) criticality predicts the absence of length scales. The curvature scalar of 3-space is dimensional quantity must vanish - hence flatness. TGD Universe is indeed quantum critical! This fixes the value spectrum of various coupling parameters.

The original TGD inspired answers to the basic questions would be following.

1. What were the initial conditions? In TGD Universe the primordial phase was a gas of cosmic strings in vicinity of the boundary of very big causal diamond (for the observer in recent cosmology). The boundary of CD - having M^4 given by the intersection of future and past directed light-cones - consists of two pieces of light-cone boundary with points replaced with CP_2). The gas is associated with the second piece of the boundary.

   Horizon size for M^4 light-cone is infinite and the hierarchy of Planck constants allows quantum coherence in arbitrarily long scales for the gas of cosmic strings forming the primordial state. This could explain constant cosmic temperature both in classical and quantum sense (both explanations are needed by quantum classical correspondence).

2. Inflationary period is replaced with the phase transition giving to space-time sheets with 4-D Minkowski space projection: the space-time as we know it. The basic objects are magnetic flux tubes which have emerged from cosmic strings as the M^4 projection has thickened from string world sheet to 4-D region. These cosmic strings decay partially to elementary particles at the end of the counterpart of inflationary period. Hence Kähler magnetic energy replaces the energy of the inflaton field. The outcome is radiation dominated cosmology.

3. The GRT limit of TGD replaces the many-sheeted space-time with a region of M^4 made slighly curved. Could one model this GRT cosmology using as a model single space-time sheet? This need not make sense but one can try.

   Criticality states that mass density is critical as in inflationary scenario. Einstein's equations demand that the curvature scalar for Lorentz invariant RW cosmology vanishes. It turns out that one can realize this kind of cosmology as vacuum extremal of Kähler action. The resulting cosmology contains only single free parameter: the duration of the transition period. 3-space is flat and has critical mass density as given by Einstein tensor.

   One might hope that this model could describe quantum criticality in all scales: not only the inflationary period but also the accelerating expansion at much later times. There is an exponentially fast expansion but it need not smooth out fluctuations now since the density of cosmic strings and temperature are essentially constant from beginning. This is what also inflationary models according to Steinhardt force to conclude although the original idea was that inflation produces the smoothness.

4. The energy of inflaton field is in this scenario replaced with the magnetic energy of the magnetic flux tubes obtained from cosmic strings (2-D M^4 projection). The negative "pressure" of the critical cosmology would microscopically corresponds to the magnetic tension along flux tubes.

5. Quantum fluctuations are present also in TGD framework but quantum coherence made possible by $h_{gr} = h_{eff} = n \times h$ dark matter saves the situation in arbitrary long scales. Dark matter as large $\hbar$ phases replaces the multiverse. Dark matter exists! Unlike multiverse!

Consider now the twistor lift of this picture. The twistorial lift of the Kähler action adds by dimensional reduction to the 4-D Kähler action a volume term proportional to dimensional constant and one expects breaking of criticality and indeed the critical vacuum extremal of Kähler action fails to be a minimal surface as one can verify by a simple calculation. The value of cosmological constant is very small in the recent cosmology but the Kähler action of its vacuum extremal vanishes. What ways out of the difficulty can one imagine?

1. Should one just give up the somewhat questionable idea that critical cosmology for single space-time sheet allows to model the transition from the gas of cosmic strings to radiation dominated cosmology?

2. Should one consider small deformations of the critical vacuum extremal and assume that Kähler action dominates over the volume term for them so that it one can speak about small deformations of the critical cosmology is a good approximation? The average energy density associated with the small deformations - say gluing of smaller non-vacuum space-time sheetes to the background - would be given by Einstein tensor for critical cosmology.

3. Or could one argue as follows? During quantum criticality the action cannot contain any dimensional parameters - this at least at the limit of infinitely large CD. Hence the cosmological constant defining the coefficient of the volume term must vanish. The corresponding (p-adic) length scale is infinite and quantum fluctuations indeed appear in arbitarily long scales as they indeed should in quantum criticality. Can one say that during quantum critical phase transition volume term becomes effectively vanishing because cosmological constant as coupling constant vanishes.

   One can argue that this picture is an over-idealization. It might however work at GRT limit of TGD where size scale of CD defines the length scale assignable to cosmological constant and is taken to infinity. Thus vacuum extremal would be a good model for the cosmology as described by GRT limit.

As already described, there is also second problem. One has two explanations for the vacuum energy and negative pressure. First would come from the Kähler magnetic energy and magnetic tension and second from cosmological constant associated with the volume term. I have considered the possibility that these explanations are equivalent. The first one would apply to the magnetic flux tubes near to vacuum extremals and carrying vanishing magnetic monopole flux. Second one would apply to magnetic flux tubes far from vacuum extremals and carrying non-vanishing monopole flux. One can consider quantum criticality in the sense that these two flux tubes correspond to each other in 1-1 manner meaning that their M^4 projections are identical and they have same string tension.

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