TGD and Cosmology

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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 labelled 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 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 labelled 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 zero energy ontology 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 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.

2. Dark matter hierarchy and hierarchy of Planck constants

Dark matter revolution with levels of the hierarchy labelled 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.

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 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. 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.

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

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 labelling 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. Equivalence Principle in TGD framework

The failure of Equivalence Principle in TGD Universre was something which was very difficult to take seriously and this led to a long series of ad hoc constructs trying to save Equivalence Principle instead of trying to characterize the failure, to find out whether it has catastrophic consequences, and to relate it to the recent problems of cosmology, in particular the necessity to postulate somewhat mysterious dark energy characterized by cosmological constant. The irony was that all this was possible since TGD allows to define both inertial and gravitational four-momenta and generalized gravitational charges assignable to isometries of $M^4 \times CP_2$ precisely.

It indeed turns out that Equivalence Principle can hold true for elementary particles having so called CP_2 type extremals as space-time correlates and for hadrons having string like objects as space-time correlates. This is more or less enough to have consistency with experimental facts. Equivalence Principle fails for vacuum extremals representing Robertson-Walker cosmologies and for all vacuum extremals representing solutions of Einstein's equations. The failure is very dramatic for string like objects that I have used to call cosmic strings. These failures can be however understood in zero energy ontology.

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.

Many-sheeted fractal cosmology containing both hyperbolic and critical space-time sheets based on cosmic strings suggests an explanation for several puzzles of GRT based cosmology such as dark matter problem, origin of matter antimatter asymmetry, the problem of cosmological constant and mechanism of accelerated expansion, the problem of several Hubble constants, and the existence of stars apparently older than the Universe. Under natural assumptions TGD predicts same optical properties of the large scale Universe as inflationary scenario does. The recent balloon experiments however favor TGD inspired cosmology.

1 Introduction

TGD inspired cosmology in its recent form relies on an ontology differing dramatically from that of GRT based cosmologies. Zero energy ontology 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 labelled 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.

1.1 Zero energy cosmology

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 [C1, D3] indeed leads naturally to zero energy ontology 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 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 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 [18] have space-time correlates [C8, C9]. There is a canonical hierarchy of Jones inclusions labelled by finite subgroups of SU(2)[17] 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 axies. 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 [C9]. 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 [C9]. 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 [C9, J1] and recently reported strange properties of graphene [74]. Also the tedrahedral and icosahedral symmetries of water molecule clusters could have similar interpretation [75, F10].

A further fascinating possibility is that the observed indications for Bohr orbit quantization of planetary orbits [71] could have interpretation in terms of gigantic Planck constant for underlying dark matter [D7] 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 modelled 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.

1.3 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.

1.4 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 labelling 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 [D5].

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 [D7]. 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.

1.5 Equivalence Principle in TGD framework

The motivation for TGD as a Poincare invariant theory of gravitation was that the notion of four-momentum is poorly defined in curved space-time since corresponding Noether currents do not exist. There however seems to be a fundamental obstacles against the existence of a Poincare invariant theory of gravitation related to the notions of inertial and gravitational energy.

1. The conservation laws of inertial energy and momentum assigned to the fundamental action would be exact in this kind of a theory. Gravitational four-momentum can be assigned to the curvature scalar as Noether currents and is thus completely well-defined unlike in GRT. Equivalence Principle requires that inertial and gravitational four-momenta are identical. This is satisfied if curvature scalar defines the fundamental action principle crucial for the definition of quantum TGD. Curvature scalar as a fundamental action is however non-physical and had to be replaced with so called Kähler action.

2. One can question Equivalence Principle because the conservation of gravitational four-momentum seems to fail in cosmological scales. It must be however emphasized that here zero energy ontology implying that the notions of inertial and four-momenta are length scale dependent concepts could change the situation.

3. For the extremals of Kähler action the Noether currents associated with curvature scalar are well-defined but non-conserved. Also for vacuum extremals satisfying Einstein's equations gravitational energy momentum is not conserved and non-conservation becomes large for small values of cosmic time. This looks fine but the problem is whether the failure of Equivalence Principle is so serious that it leads to conflict with experimental facts.

The failure of Equivalence Principle was something which I could not take seriously and I ended up with a long series of ad hoc constructs trying to save Equivalence Principle instead of trying to characterize the failure, to find out whether it has catastrophic consequences, and to relate it to the recent problems of cosmology, in particular the necessity to postulate somewhat mysterious dark energy characterized by cosmological constant. The irony was that all this was possible since TGD allows to define both inertial and gravitational four-momenta and generalized gravitational charges assignable to isometries of $M^4 \times CP_2$ precisely.

It indeed turns out that Equivalence Principle can hold true for elementary particles having so called CP_2 type extremals as space-time correlates and for hadrons having string like objects as space-time correlates. This is more or less enough to have consistency with experimental facts. Equivalence Principle fails for vacuum extremals representing Robertson-Walker cosmologies and for all vacuum extremals representing solutions of Einstein's equations. The failure is very dramatic for string like objects that I have used to call cosmic strings. These failures can be however understood in zero energy ontology.

1.6 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.

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.

1.7 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.

   e) Certain problems of the cosmology such as the questions why some stars seem to be older than the Universe, the claimed time dependence of the fine structure constant, the generation of matter antimatter asymmetry, and the problem of the fermion families, are discussed.

4. Simulating Big Bang in laboratory is the title of the last section. The motivation comes from the observation that critical cosmology could serve as a universal model for phase transitions.

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-time defines a hierarchy of smoothed out space-times

The notion of quantum average space-time obtained by smoothing out details below the scale of resolution was inspired by renormalization philosophy and for long time I regarded it as a fictive concept. The rough idea was that quantum average effective space-times correspond to the absolute minima 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 is 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 $J^{\alpha}_{a\#}$ serving as sources of classical electro-weak and color gauge fields (see Fig. 2.1). 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.

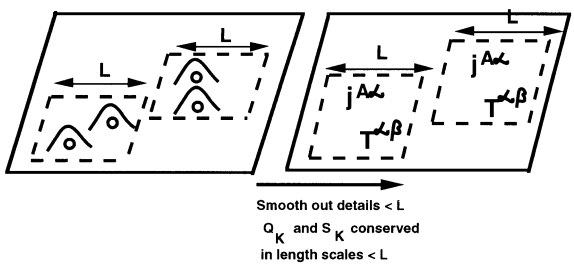

Figure 1: Intuitive definition of length scale dependent space-time

During development of the many-sheeted space-time concept it has become obvious that the notions of classical space-time and of smoothing out of details are not only activities 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 labelled 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 absolute minimum value for 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 metri

4. rather than vice versa. Since the dynamics of the induced EYM fields is dictated by the absolute minimization of Kähler action, EYM equations cannot in general be satisfied 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.

5. 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 [C8, C9]. 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 [C3].

6. Dark matter hierarchy whose levels are labeled by the values of Planck constant brings in an additional complication [C9, C3, D3]. Planck constant actually labels the "field bodies" mediating various interactions and gravitational field bodies have a gigantic value of Planck constant.

   The realization of this hierarchy at the level of imbedding space means the replacement of the 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.

   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.

   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.

2.2 Robertson-Walker cosmologies

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.

2.2.1 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 [19]. 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.

2.2.2 Imbeddability requirement for RW cosmologies

Standard Robertson-Walker cosmology is characterized by the line element [21]

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

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

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

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

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

$$\begin{aligned} a &= \sqrt{(m^0)^2 - r_M^2} \ , \\ r_M &= ar \ . \end{aligned} \tag{3}$$

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 $M^4_+ \rightarrow CP_2$ defines imbedding

$$s^k = f^k(a) \ . \tag{4}$$

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

$$\rho = \frac{3}{8\pi G a^2}(\frac{1}{g_{aa}} + k) \ . \qquad (5)$$

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

$$\begin{aligned} \phi &= f(a) \ , \\ g_{aa} &= 1 - \frac{R^2}{4}(\partial_a f)^2 \ . \end{aligned} \qquad (6)$$

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.

2.2.3 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

$$\begin{aligned} sin(\Theta) &= \frac{a}{a_1} \ , \\ (\partial_r \Phi)^2 &= \frac{1}{K_0}\left[\frac{1}{1-kr^2} - \frac{1}{1+r^2}\right] \ , \\ K_0 &= \frac{R^2}{4a_1^2} \ , \ \ k = 0, 1 \ , \end{aligned} \qquad (7)$$

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

$$\partial_r \Phi = \pm \sqrt{\frac{1}{K_0}\left[\frac{1}{1-kr^2} - \frac{1}{1+r^2}\right]} \ . \tag{8}$$

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

$$ds^2 = da^2 - a^2\left(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right) \ . \tag{9}$$

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 $k=1$.

$$\begin{aligned} g_{aa} &= 1-K \ , \\ K &\equiv K_0 \frac{1}{(1-u^2)} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{10}$$

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

$$\begin{aligned} \rho &= \frac{3}{8\pi G a^2}\left(\frac{1}{g_{aa}} + k\right) \ , \ k = 0, \pm 1 \ , \\ \frac{1}{g_{aa}} &= \frac{1}{1-K} \ , \\ p &= -\left(\rho + \frac{a\partial_a \rho}{3}\right) = -\frac{\rho}{3} + \frac{2}{3}K_0 u^2 \frac{1}{(1-K)(1-u^2)^2}\rho_{cr} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{11}$$

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.

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 $a \rightarrow 0$. Thus, instead of Big Bang one has 'Silent Whisper' gradually amplifying to Big Bang. The imbedding fails at the limit $a \rightarrow a_1$. 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 ($p \rightarrow -\rho/3$) 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 $\theta \rightarrow \pi/2$. 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.

2.2.4 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 guaranteing 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

$$
\begin{aligned}
r &= \sqrt{\frac{X}{1-X}} \ , \\
X &= D|k+u| \ , \\
u &\equiv cos(\Theta) \ , \quad D = \frac{r_0^2}{1+r_0^2} \times \frac{1}{C} \ , \quad C = |k + cos(\Theta_0)| \ .
\end{aligned} \tag{12}
$$

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

$$
\begin{aligned}
ds^2_{eff} &= \frac{R^2}{4}[s^{eff}_{\Theta\Theta} d\Theta^2 + s^{eff}_{\Phi\Phi} d\Phi^2] \ , \\
s^{eff}_{\Theta\Theta} &= X \times \left[\frac{(1-u^2)}{(k+u)^2} \times \frac{1}{1-X} + 1 - X \right] \ , \\
s^{eff}_{\Phi\Phi} &= X \times \left[(1-X)(k+u)^2 + 1 - u^2 \right] \ .
\end{aligned} \tag{13}
$$

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

$$
sin(\Theta) = ka \quad \rightarrow \quad \sqrt{s^{eff}_{\Phi\Phi}} = ka \ . \tag{14}
$$

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

$$g_{aa} = 1 - \frac{R^2k^2}{4} \frac{s^{eff}_{\Theta\Theta}}{\frac{d\sqrt{s^{eff}_{\Phi\Phi}}}{d\Theta}} \quad (15)$$

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.

2.2.5 String dominated cosmology

A particularly interesting cosmology is 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:

$$g_{aa} = K < 1 \ . \quad (16)$$

The Hubble constant for this cosmology is given by

$$H = \frac{1}{\sqrt{K}a} \ , \quad (17)$$

and the so called acceleration parameter [21] k_0 proportional to the second derivative $\ddot{a}$ therefore vanishes. Mass density and pressure are given by the expression

$$\rho = \frac{3}{8\pi G K a^2}(1-K) = -3p \ . \quad (18)$$

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.

2.2.6 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

$$\partial_a(G^{aa}\partial_a\phi\sqrt{g}) = 0 , \tag{19}$$

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

$$\begin{aligned} g_{aa} &= \frac{(1-2x)}{(1-x)} , \\ x &= (\frac{C}{a})^{2/3} . \end{aligned} \tag{20}$$

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

$$\begin{aligned} \rho &= \frac{3}{8\pi G a^2}\frac{x}{(1-2x)} , \\ p &= -(\rho+\frac{a\partial_a\rho}{3}) = -\frac{\rho}{9}\left[3-\frac{2}{(1-2x)}\right] . \end{aligned} \tag{21}$$

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 [D3]. 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.

2.2.7 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

$$E = \int \rho g^{aa}\partial_a m^0\sqrt{g}dV . \tag{22}$$

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

$$X \equiv \frac{(dE/da)_{vap}}{E} = \frac{(dE/da + \int |g^{rr}|p\partial_r m^0\sqrt{g}d\Omega)}{E} , \tag{23}$$

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

$$X = \frac{\partial_a(\rho a^3/\sqrt{g_{aa}})}{(\rho a^3/\sqrt{g_{aa}})} + \frac{3pg_{aa}}{\rho a} \ . \tag{24}$$

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

$$\begin{aligned} X &= X_1 + X_2 \ , \\ X_1 &= \frac{\partial_a(\rho a^3/\sqrt{g_{aa}})}{(\rho a^3/\sqrt{g_{aa}})} \ , \\ X_2 &= \frac{pg_{aa}}{\rho a} \times \frac{3+2r^2}{(1+r^2)^{3/2}} \ . \end{aligned} \tag{25}$$

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

$$\begin{aligned} &X = X_1 + X_2 \ , \\ &X_1 = \frac{1}{a}\left[1 + 3K_0u^2\frac{1}{1-K}\right] \ , \\ &X_2 = -\frac{1}{3a}\left[1 - K - \frac{2K_0u^2}{(1-u^2)^2}\right] \times \frac{3+2r^2}{(1+r^2)^{3/2}} \ , \\ &K = \frac{K_0}{1-u^2} \ , \quad u = \frac{a}{a_0} \ , \quad K_0 = \frac{R^2}{4a_0^2} \ . \end{aligned} \tag{26}$$

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 $a \to 0, r \to \infty$ one has $X = 1/a$ which means that topological condensation is present already at the limit $a \to 0$.

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 $a \to 0$ 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

$$\rho \ < \ \frac{k}{a^{2+2/3}} \tag{27}$$

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.

2.3 Cosmic strings and cosmology

The vapor phase density of cosmic strings is source of all matter and radiation in TGD based cosmology and the model for cosmic strings has forced to question all cherished assumptions including positive energy ontology, Equivalence Principle, and positivity of gravitational energy. Therefore cosmic strings deserve a separate discussion. More details can be found in [D5].

2.3.1 Zero energy ontology and cosmic strings

There are two kinds of cosmic strings: free and topological condensed ones.

1. Free cosmic strings are not absolute minima of the Kähler action (the action has wrong sign). $P3$ would favor cosmic strings and also their electric duals if they exist. Since the magnetic field of cosmic string corresponds to CP_2 degrees of freedom with Euclidian signature electric duals do not probably exist.

2. 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 mechanism need not be local.

The most convincing cancelation mechanism relies on zero energy ontology. If the sign of the Kähler action depends on time orientation it would be opposite for positive and negative energy space-time sheets and the actions associated with them would cancel if the field configurations are identical. Hence zero energy states would naturally have small Kähler action. Obviously this mechanism is non-local.

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.

The earlier picture was based on dynamical cancellation mechanism involving generation of strong Kähler electric fields in the condensation whose action compensated for Kähler magnetic action [16].

2.3.2 Failure of Equivalence Principle for cosmic strings

The empirical fact is that inertial 4-momentum is conserved whereas gravitational momentum is not. This suggests that inertial momentum corresponds to Noether charge associated with Kähler action and gravitational momentum to that associated with curvature scalar for the induced metric. This means that Equivalence Principle does not hold true in general. A detailed analysis demonstrates that Equivalence Principle can remain intact for elementary particles and light string like objects such has hadrons.

For string like objects of form $X^2 \times Y^2 \subset M^4 \times CP_2$, X^2 orbit or string and Y^2 holomorphic surface of CP_2, gravitational mass contains very large contribution coming from the curvature of Y^2 when the genus of Y^2 is different from $g = 1$. For sphere the gravitational string tension is positive and equal to $T_{gr} = dM/dl = 1/4G$. The angle defect would be 2π for the standard almost everywhere flat exterior metric so that it does not make sense. It is however possible to find exterior metric as an extremal of curvature scalar conforming with Newtonian intuition. For $g > 1$ the string tension is $(1-g)/4G$ and negative for $g > 1$. In this case angle deficit is transformed to angle excess $(g-1)2\pi > 2\pi$, which make sense also in case of flat exterior metric which however as such is not imbeddable to $M^4 \times CP_2$.

Topological condensation creates wormhole contacts having interpretation as gauge bosons which contribute to gravitational string tension. The natural assumption is that this contribution has the string tension due to Kähler action as a space-time correlate. Thus Equivalence Principle holds for $g = 1$ but not for $g \neq 1$ which corresponds to purely gravitational energy having no inertial counterpart.

It is however possible that in sufficiently long length scales the gravitational energies of $g > 1$ and and $g \leq 1$ strings sum up to zero so that cosmic strings would make them effectively invisible and Equivalence Principle would hold true. This could happen in length scales longer than the size $L \sim 10^8$ ly of large voids [57].

2.3.3 Topological condensation of cosmic strings

1. Exterior metrics of topologically condensed $g > 1$ strings

If the sign of the gravitational string tension is negative the simple imbedding of the metric existing for positive string tension ceases to exist. There exists however a different imbedding for which angle excess is in a good approximation same as for the flat solution. The solution is not flat anymore and this implies outwards radial gravitational acceleration. The imbedding of the exterior metric also fails beyond a critical radius. This is not the only possible exterior metric: also non-flat exterior metric are possible and look actually more plausible and also this metric implies radial outwards acceleration as one might indeed expect. What remains to be shown that these metrics do not only yield small angle defect but are also consistent with Newtonian intuitions as the constant velocity spectrum for distant stars around galaxies suggests.

The natural interpretation would be as a mechanism generating large void around a central cosmic string having $g > 1$ and negative string tension and containing at its boundary $g = 1$ positive energy cosmic strings with string tension equal to Kähler string tension. Since angle surplus instead of angle deficit is predicted for $g > 1$ strings, lense effect transforms in this case to angle divergence and one avoids the basic objection against big cosmic strings. The emergence of preferred axes defined by $g > 1$ strings in the scale of large void could relate to the anomalies observed in Cosmic Microwave Background.

Negative gravitational energy of $g > 1$ cosmic strings could be regarded as that part of gravitational energy which causes the accelerated cosmic expansion by driving galactic strings to the boundaries of large voids which then induces phase transition increasing the size of the voids. This kind of acceleration is encountered already at the level of Newton's equations when some of the gravitational masses are negative.

2. Exterior metrics of topologically condensed $g = 1$ strings

One cannot assume that the exterior metric of the galactic $g = 1$ strings is the one predicted by assuming $G = 0$ 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. This lensing has not been observed.

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.

2.3.4 Dark energy is replaced with dark matter in TGD framework

The first thing that comes in mind is that negative gravitational energy could be the TGD counterpart for the positive dark vacuum energy known to dominate over the mass density in cosmological length scales and believed to cause the accelerated cosmic expansion. This argument is wrong.

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. 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.

2. The essential characteristic of dark energy is its negative pressure. Negative gravitational energy could effectively create this negative pressure during phase transitions increasing the size of large voids. Since negative gravitational mass would be basically responsible for the accelerated expansion, one can assume that dark energy is actually dark matter.

3. Note that the pressure is negative during critical period. This is however interpreted as a correlate for the expansion caused by the phase transition increasing Planck constant rather than being due to positive cosmological constant or quintessence with negative pressure.

2.3.5 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 negative pressure now. 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.

Classically one can understand the occurrence of the phase transitions increasing the size of the void as resulting when the galactic strings end up to the boundary of the large void in the repulsive gravitational field of the big string.

2.3.6 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 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. The key observation is that vacuum extremals as such are not physically acceptable: small deformations of vacuum extremals to non-vacua are required. The simplest deformation of this kind would induce a radial Kähler electric field and thus 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.

Either $g = 1$ galactic cosmic strings or $g > 1$ big cosmic strings at the centers of galactic voids or both could generate the asymmetry. 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.

1. The ratio $\epsilon = G/R^2 \simeq 4 \times 10^{-8}$ is certainly a fundamental constant in TGD Universe. By replacing R with $2\pi R$ would give $\epsilon = G/(2\pi R)^2 \simeq 1.0 \times 10^{-9}$. This option looks nice since it would allow $g = 1$ cosmic strings to generate the asymmetry.

2. The parameter ϵ characterizing the ratio of the densities of inertial energy and gravitational energy has for $g \neq 1$ cosmic strings the upper bound

$$\epsilon_{max} = \frac{1}{1-g} \times \frac{G}{8\alpha_K R^2} \simeq .52 \times 10^{-6} \times \frac{1}{1-g} \quad . \tag{28}$$

In this case $g = 1$ strings are excluded as generator of the asymmetry.

This bound is for $\alpha_K(p = M_{127}) = 1/104$ corresponding to electron's p-adic length scale which would correspond to the p-adic prime labelling the space-time sheets mediating gravitational interaction [C5]. The motivation for this is that elementary bosons in general seem to correspond to Mersenne primes and M_{127} is the largest not completely super-astrophysical Mersenne prime.

Unfortunately, for $g = 2$ the ratio is roughly by a factor 2^9 larger than the baryon-to-photon ratio and the following attempts to save this option are not very impressive.

i) Correct order of magnitude for ϵ would be obtained for $p \simeq 2^k$, $k = 137$, which happens to correspond to atomic length scale. This would give $r \simeq 5 \times 10^{-10}$.

ii) $g \sim 2^9$ for all big cosmic strings seems somewhat artificial. The model assumes $G \propto L_p^2 \propto 2^k$ by p-adic length scale hypothesis.

2.3.7 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). The CP breaking at the level of CKM matrix in turn might have explanation in terms of the hadronic Kähler electric fields.

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 [C5].

2.3.8 Development of strings in the string dominated cosmology

The development of the string perturbations in the Robertson Walker cosmology has been studied [22] 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 [22]

$$\begin{aligned} (\partial_\tau + \frac{2\dot{a}}{a})(\dot{y}U) &= \partial_z(y'U) \ , \\ U &= \frac{1}{\sqrt{1+(y')^2-\dot{y}^2}} \ . \end{aligned} \tag{29}$$

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

$$\ddot{y} + \frac{2}{\sqrt{K}}\dot{y} - y'' = 0 \ . \tag{30}$$

The separable solutions of this equation are of type

$$\begin{aligned} y &= g(a)(C\sin(kz) + D\cos(kz)) \ , \\ g(a) &= (\frac{a}{a_0})^r \ . \end{aligned} \tag{31}$$

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

$$r = -\frac{1}{\sqrt{K}}(1 \pm \sqrt{1 - k^2 K}) \ . \tag{32}$$

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 [22] must satisfy the following conditions

$$l_J < L < l_H \ , \tag{33}$$

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 [22]

$$l_J \simeq 10 v_s t \ . \tag{34}$$

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.

2.4 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.

2.4.1 The new view about second law

Quantum classical correspondence suggests negative and positive energy strings tend to dissipate backwards in opposite directions of the geometric time in their geometric degrees of freedom. This would mean a continual competition between ordinary dissipation of tightly paired positive energy strings. Time reversed dissipation of negative energy strings looks from the point of view of systems consisting of positive energy matter self-organization and even self assembly and and also here the same competition would prevail.

This 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. Entropic state could relate to space-time sheets with negative time orientation but there would be also negentropic state corresponding to the positive energy matter. The dissipative evolution of matter at space-time sheets with positive time orientation (space-time sheets of positive energy cosmic strings) would obey second law and evolution of space-time sheets with negative time orientation (in particular negative energy cosmic strings) its geometric time reversal. Second law would hold true in the standard sense as long as one can neglect the interaction with negative energy matter and strings. TGD inspired theory of consciousness predicts p-adic evolution and this would mean that negentropic tendency would win. Perhaps matter antimatter asymmetry reflects this.

2. 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.

3. 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.

4. 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 two alternative solutions of this puzzle.

   i) 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. The self organizing tendency of negative energy cosmic strings competing with the opposite tendency of positive energy strings and ordinary matter could give rise to kind of gravitational homeostasis. Although blackhole like structure could result as outcome of gravitational self-organization they would not be sinks of information but have complex internal information carrying structure.

ii) 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 $log(p)$.

2.4.2 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 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 $R \sim 10^4$ Planck times corresponds is CP_2 time. Before this moment there is no macroscopic space-time but only vapor phase consisting of cosmic strings 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 might generate the matter antimatter asymmetry, they lead to the formation of the large voids and galaxies, they give rise to the galactic dark matter and the 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 $a \rightarrow 0$ 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

$$\rho \propto \frac{1}{a^2} \ , \tag{35}$$

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

$$\rho = n\frac{3}{8\pi G a^2} \ . \tag{36}$$

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

$$n = 1 \ . \tag{37}$$

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 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 $1/a^2$.

2.4.3 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 $T_H \sim 1/R$, where R is CP_2 radius of order $R \sim 10^4\sqrt{G}$ and thus considerably smaller than Planck temperature.

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 $\rho \propto 1/a^4$, $p = \rho/3$ [22]. 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 [23]. Therefore, if the value of the mean square velocity approaches light velocity, effective radiation dominance results even when strings dominate [24]. 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 $T_R \simeq .3\text{eV}$ at the time about $a_R \sim 3\times 10^7$ 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

$$\begin{aligned} a_F &= a_R \frac{T_R}{T_H} \ , \\ T_H &= \frac{n}{R} \ , \qquad a_R \sim 3\times 10^7 \ y \ , \quad T_R = .27 \ eV \ . \end{aligned} \tag{38}$$

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 [D7] 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.

2.4.4 What about thermodynamical implications of dark matter hierarchy?

The previous discussion has not mentioned dark matter hierarchy labelled 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 [10, M3].

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 [10]) 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.

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.

3.1 Primordial cosmology

TGD inspired cosmology has primordial phase in which only vapor phase containing only cosmic strings 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

$$\begin{aligned} \rho_V &= \frac{3}{8\pi G a^2} \ , \\ p &= -\frac{\rho}{3} \ . \end{aligned} \tag{39}$$

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.

It must be however added that the conservation of gravitational four-momentum is an unnecessarily strong assumption and one can quite well consider the possibility that sub-cosmologies are generated from vacuum spontaneously.

3.2 Critical phases

The absolute minimization 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. What happens is that space-time sheets are created and 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

$$q \quad = \quad -K_0 \frac{K_0 u^2}{1-u^2-K_0} < 0 \ \ , \ \ u = a/a_1 \ \ , \tag{40}$$

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

$$\frac{dH/ds}{H^2} = -(1+q) \ \ , \tag{41}$$

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 [D5] and shown to explain the observed jerk about 13 billion years changing deceleration to acceleration. The recently observed cold spot in cosmic microwave background [58] 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, $L(k) = l \times 2^{k/2}$, $l = R \simeq 10^4$ 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

$$\begin{aligned} T(k) &= \tfrac{n}{L(k)} \ \ , \qquad \text{for } k > k_{cr} \ \ , \\ T(k) &= T_H \sim \tfrac{1}{R} \ \ , \quad \text{for } k \leq k_{cr} \ \ . \end{aligned} \tag{42}$$

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 ($m_{CP_2} \simeq 10^{-4}$ 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

$$\rho = nT^4(k) \ , \tag{43}$$

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 [F1] for the argument why $g > 2$ particle families have ultra heavy masses). Thus it seems that the infinite number of fermion families cannot 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 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

$$s_2 \equiv \int_{a_1}^{a_1+a_2} \sqrt{g_{aa}} da \sim L(k) \ . \tag{44}$$

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 [D5]. 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 labelled 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

$$\frac{3}{4\pi}\frac{nT}{a_*^2} < \rho_s = \frac{3}{8\pi G a^2} \quad . \tag{45}$$

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

$$n < 2 \times 10^6 \times (\frac{a_*}{a})^2 \quad . \tag{46}$$

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

$$\frac{\rho_s(a)}{\rho_m a(a)} \quad = \quad n \times 1.8 \times 10^{-6}(\frac{a}{a_*})^3 \quad . \tag{47}$$

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

$$\begin{aligned} n &< 20 \ , \\ \frac{\rho_s(a)}{\rho_m} &\simeq n \times 18 \times \sqrt{10} \ . \end{aligned} \tag{48}$$

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

$$\frac{(d\rho_c/da)}{\rho_c} = -\frac{1}{2a} \sim 10^{-11}\frac{1}{year} \ . \tag{49}$$

The rate is of the same order of magnitude as the rate of energy production in Sun [21] 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 $dE_{gr}/da = 0$. 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

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

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 [19] 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 [19].

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

$$\begin{aligned} \rho &= \frac{3}{8\pi G a^2}(\frac{1}{K}-1) \ , \\ H^2 &= \frac{1}{Ka^2} \ , \end{aligned} \tag{50}$$

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

$$\begin{aligned} c_{\#} &= \sqrt{K} \simeq .93 \ , \\ \Omega \equiv \frac{\rho}{\rho_{cr}} &\simeq .16 \ . \end{aligned} \tag{51}$$

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

$$\begin{aligned} \rho_{m0} &= \rho_m(\frac{a}{a_1})^3 = \rho_s = \rho_{s0}(\frac{a}{a_1})^2 \ , \\ a_1 &= \frac{\rho_m}{\rho_s} a \sim 6 \times 10^8 \ \text{ly} \ . \end{aligned} \tag{52}$$

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

$$
\begin{aligned}
g_{aa} &= \frac{(1-2x)}{(1-x)} \quad , \\
\rho &= \frac{3}{8\pi G a^2} \frac{x}{(1-2x)} \quad , \\
x &= (\frac{a_1}{a})^{2/3} \quad .
\end{aligned} \tag{53}
$$

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 [23]: 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

$$
\rho = \frac{3}{8\pi G a^2} \frac{(\frac{a_1}{a})^{2/3}}{(1-2(\frac{a_1}{a})^{2/3})} \quad , \tag{54}
$$

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:

$$
\begin{aligned}
x &= \frac{\frac{r}{4}\frac{a_*}{a}}{1+\frac{r}{2}\frac{a_*}{a}} \simeq .16 \quad , \\
a_1 &\simeq 2 \times 10^9 \ \text{ly} \quad , \\
c_\# &\simeq .93 \quad , \\
\Omega &\simeq .16 \quad .
\end{aligned} \tag{55}
$$

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

$$q = \frac{1}{3}\frac{x}{(1-2x)(1-x)} \ . \tag{56}$$

   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 $q_0 = 1/2$ [21]. Quite recent determinations of the parameter [25] 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 [26] 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.

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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 [B4]. 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 [53].

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 seems to 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 [27, 28].

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 situation is diametric opposite of this since exponential expansion is replaced by a logarithmic expansion. This can be seen by solving proper time t in terms of M^4_+ proper time a from the equation

$$\frac{dt}{da} = \sqrt{g_{aa}} = \sqrt{1 - \frac{R^2k^2}{4}\frac{1}{1-k^2a^2}} \ . \quad (57)$$

One obtains

$$kt = \int^{sinh(ka)} du\sqrt{cosh^2(u) - \frac{R^2k^2}{4}} \simeq sinh(ka) \quad (58)$$

since $R^2k^2 \ll 1$ holds true. This gives $kt \sim sinh(ka) \sim exp(ka)$ rather than $a \sim exp(Ht)$ as in inflationary scenarios so that expansion takes place with a logarithmic slowness.

2. In the inflationary scenarios the exponential expansion destroys inhomogenities 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 $a \rightarrow 0$ 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.

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 labelling 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

$$\rho_V = \frac{3}{8\pi G a^2} . \quad (59)$$

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 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.

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

$$\begin{aligned} \frac{1}{g^H_{aa}} - 1 &= \frac{1}{1-K} \equiv \epsilon \ , \\ K &\equiv \frac{R^2}{4a_1^2}\frac{1}{(1-(\frac{a}{a_1})^2)} \ . \end{aligned} \tag{60}$$

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

$$\rho = \frac{3}{8\pi G}\epsilon\frac{a_1^{1+n}}{a^{3+n}} \ . \tag{61}$$

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

$$\begin{aligned} s_1 &= \int_0^{a_1} \sqrt{1-K} da \quad , \\ K &\equiv \frac{R^2}{4a_1^2} \frac{1}{(1-(\frac{a}{a_1})^2)} \quad . \end{aligned} \tag{62}$$

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

$$s_2 \quad = \quad \int_{a_1}^{a_1+a_2} \sqrt{g_{aa}} da \quad . \tag{63}$$

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 $l \simeq 10^4$ 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

$$s_2 = x_2 L(k(next)) - x_1 L(k) \ . \tag{64}$$

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

$$\begin{aligned} T(k) &= \tfrac{n}{L(k)} \ , \qquad \text{for } k > k_{cr} \ , \\ T(k) &= T_H \sim \tfrac{1}{R} \ , \quad \text{for } k \leq k_{cr} \ . \end{aligned} \tag{65}$$

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 ($m_{CP_2} \simeq 10^{-4}$ 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

$$\rho = nT(k)^4 \ , \tag{66}$$

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.

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 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	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

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 $r \simeq 1.1$.

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 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. Since 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 is that topological evaporation is only effective and caused by the reduction of the energy density by the absorption of negative energy virtual gravitons. Both effects might of course be involved.

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

$$a_1(p_1)\epsilon(p_1) = p \times a_1(p_2)\epsilon(p_2) \quad . \tag{67}$$

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

$$\frac{\epsilon(k_1)}{\epsilon(k_2)} = p \times 2^{(k_2-k_1)/2} \quad . \tag{68}$$

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

$$\begin{aligned} \Delta\phi_{obs} \simeq tan(\Delta\phi_{obs}) &= \frac{\sqrt{g_{\phi\phi}}\Delta\phi_r}{R(r)} \ , \\ R(r) &= \int \sqrt{g_{aa}} da = \int \sqrt{g_{rr}} \frac{dr}{da} da \end{aligned} \quad (69)$$

$R(r)$ 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

$$\begin{aligned} \frac{\Delta\phi_{obs}}{\Delta\phi_{obs}(flat)} &= \frac{R(r, flat)}{R(r)} \\ &= \frac{a - a_1}{\int_{a_1}^{a} \sqrt{g_{aa}} da} \end{aligned} \quad (70)$$

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

$$
\begin{aligned}
a-a_1 = r-r_1 \ , & \quad \text{(critical cosmology with } g_{aa}=1) \ , \\
a-a_1 \sim log(\frac{r}{r_1}) \ , & \quad \text{(hyperbolic cosmology with } g_{aa}=1) \ , \\
\frac{2}{3}ka((\frac{a}{a_R})^{1/2}-(\frac{a_1}{a_R})^{1/2}) & \\
= log(\frac{r}{r_1}) \ , & \quad \text{(matter dominance with } g_{aa}=k(\frac{a}{a_R})^{1/2}) \ .
\end{aligned}
\tag{71}
$$

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

$$
\int_{a_2}^{a} \sqrt{g_{aa}}da \quad = \quad \sum_i [\Delta a_0(i) + s_2(i)] \quad . \tag{72}
$$

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 guaranteing 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

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

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

$$\begin{aligned} s_R &= \int_{a_1}^{a_R} \sqrt{g_{aa}} da \ , \\ g_{aa} &\simeq 10^{-3} \frac{a^2}{a_R^2} \ . \end{aligned} \tag{73}$$

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 [51].

The first year Wilkinson microwave anisotropy probe observations [49] 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 [50] 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 [45] 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 [44] led to the same result. According to the article of Luminet [46], 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 [53]. 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 [47, 48], 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 modelled 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 labelling 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 [30, 31] 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. [32]. This would suggest that some additional effect is involved and TGD inspired bet have been already described.

5 Some problems of cosmology

In this chapter some problems, most of them common to both standard and TGD inspired cosmology, are discussed.

5.1 Why some stars seem to be older than the Universe?

There exists experimental evidence that some stars are older than the Universe [29, 38, 34]. A related problem is the problem of the two Hubble constants. These paradoxical results can be understood in TGD inspired cosmology. In TGD light can propagate via several routes. In the topological condensate light ray can propagate along one of the many curved space-time sheet as a small condensed particle and in the vapor phase as a small 3-surface in imbedding space $H = M^4_+ \times CP_2$, where M^4_+ is future light cone of M^4. The time needed to travel from point A to point B is shorter in the vapor phase than in any space-time surface since the geodesic length along the space-time surface in the induced metric is obviously longer than in free Minkowski space. This time depends also on the space-time sheet so that entire spectrum of effective light velocities and Hubble constants results. The failure to distinguish between vapor phase photons and photons propagating along various space-time sheets leads to the paradox as following arguments shows and possibly also to the problem of two (or in fact more than two) different Hubble constants. The possibility of the vapor phase photons or photons propagating along almost flat space-time sheets emitted by the objects outside the space-time horizon of 'our' space-time sheet explains also objects with anomalously large red shifts.

5.1.1 Basic facts

To understand these results one must study TGD based cosmology in more quantitative level.

1. The most general cosmological imbedding of M^4_+ to $M^4_+ \times CP_2$, is of form

$$
\begin{aligned}
s^k &= s^k(a) \ , \\
g_{aa} &= 1 - s_{kl}\frac{ds^k}{da}\frac{ds^l}{da} \ , \\
ds^2 &= g_{aa}da^2 - a^2\left(\frac{dr^2}{1+r^2} + r^2 d\Omega^2\right) \ . \qquad (74)
\end{aligned}
$$

   Here s_{kl} is CP_2 metric tensor and describes always expanding cosmology with subcritical or at most critical mass density.

2. The age of the Universe defined as M^4_+ proper time a of the co-moving observer (the co-moving observer on the space-time surfaces is also co-moving in M^4_+) is larger than the age defined as the proper time $s(a)$ of the co-moving observer on space-time surface. For the matter dominated Universe one has $g_{aa} = Ka$, which gives

$$
\frac{age(cond)}{age(vapor)} = \frac{s(a)}{a} = \frac{2}{3}\sqrt{g_{aa}} \ , \qquad (75)
$$

   for the ratio of the ages.

3. The recent value of g_{aa} can estimated from the expression for the mass density in the expanding cosmology

$$\begin{aligned} \rho &= \frac{3}{8\pi G}(\frac{1}{g_{aa}}+k) \ , \\ k &= -1 \ . \end{aligned} \quad (76)$$

   $k=0$ mass density corresponds to the critical mass density ρ_c. The mass density is believed to be a fraction of order $\epsilon = 0.1-0.5$ of the critical mass density and this gives estimate for $\sqrt{g_{aa}}$:

$$\begin{aligned} \sqrt{g_{aa}} &= \sqrt{1-\epsilon} \ , \\ \epsilon &= \frac{\rho}{\rho_c} \ . \end{aligned} \quad (77)$$

   $\sqrt{g_{aa}} = 2/3$ suggested by the proposed solution to the Hubble constant discrepancy gives $\epsilon = \frac{9}{4}$. $\epsilon = .1$ gives $\sqrt{g_{aa}} \simeq .95$.

4. The ratio of the condensate travel time to the vapor phase travel time for short distances is given by

$$\frac{\tau(cond)}{\tau(vapor)} = \frac{1}{\sqrt{g_{aa}}} \ . \quad (78)$$

   This effect is in principle observable. The effect provides also a means of measuring the mass density of the Universe.

5. The light travelling in the vapor phase can reach the observer from a region, which is the intersection of the past light cone of the observer with the boundary of M^4_+ and therefore finite region of M^4. The M^4 radius of this region in the rest frame of the observer is equal $r_M = a/2$ by elementary geometry.

6. For a null geodesic of the space-time surface representing cosmology, starting at (a_0, r) and ending at $(a, 0)$, one has

$$\begin{aligned} & r = sinh(X) \ , && \text{(hyperbolic cosmology)} \ , \\ & r = X \ , && \text{(critical cosmology)} \ , \\ & X = \int_{a_0}^{a} \frac{\sqrt{g_{aa}}}{a} da \ . && \end{aligned} \quad (79)$$

   If g_{aa} approaches zero for $a_0 \to 0$, as it does for the radiation dominated cosmology, the integral defining X is finite. This means that the value of $r_M(a_0)$ (M^4 distance of the object from the observer) approaches zero at this limit. All radiation from the moment of the big bang comes from the tip of the light cone. The very early cosmology with a critical mass density corresponds to $g_{aa} = 1-K$, K a very small number, and also in this case the radiation comes from the origin.

5.1.2 Maximum Minkowski distance from which light can propagate

It is interesting to find the maximum value of M^4_+ distance r_M from which it is possible to receive information in various cosmologies. The radius $r_M(a_0)$ has maximum for some finite value of a_0 and this radius defines the M^4 radius of the Universe observed using the condensate photons. For a_0 corresponding to maximum the condition

$$\begin{aligned} \sqrt{g_{aa}} &= tanh(X) \ , \ \text{(hyperbolic cosmology)} \ , \\ \sqrt{g_{aa}} &= X \ , \ \text{(critical cosmology)} \ . \end{aligned} \tag{80}$$

The maximum corresponds to a rather large value of a_0. Consider now various cases.

i) In case of matter dominated cosmology one has $g_{aa} = Ka$ and one has the condition

$$u_0 = tanh(2(u-u_0)) \simeq 2(u-u_0) \ , \quad u = \sqrt{Ka} \ , \quad u_0 = \sqrt{Ka_0} \ . \tag{81}$$

This gives in good approximation

$$u_0 = r = \tfrac{2}{3}u \ , \quad a_0 = \tfrac{4}{9}a \ , \quad r^0_M = \tfrac{8}{27}ua = \tfrac{16}{81}\sqrt{Ka} \times a \ . \tag{82}$$

ii) In case of vapor phase and also for asymptotic cosmology in the limit of flatness one obviously has

$$r^0_M = a \ . \tag{83}$$

iii) In case of critical cosmology with $g_{aa} = 1$ one has

$$a_0 = \tfrac{a}{e} \ , \quad r_0 = 1 \ , \quad r^0_M = \tfrac{a}{e} \ . \tag{84}$$

The value of r^0_M is clearly smallest in matter dominated cosmology.

5.1.3 Many-sheeted space-time allows several snapshots from the evolution of astrophysical objects

Vapor phase photons and condensate photons propagating along various space-time sheets provide in principle a possibility to obtain simultaneous information about the astrophysical object in various different phases of its development. For an object situated at distance r and observed at $(a, r=0)$, the emission moments a_0 and $a_1 > a_0$ (in Minkowski proper time) for the condensate photon and vapor phase photon are related by the formula

$$\frac{a}{a_1} = exp(2\sqrt{K_1}(a^{1/2} - a_0^{1/2})) \ . \tag{85}$$

in the matter dominated cosmology $g_{aa} = K_1 a$ ($K_1 a \sim 1$). Hence a sufficiently nearby Super Nova would provide a test for this effect. The first burst of light corresponds to vapor phase photons and subsequent bursts to the condensate photons. The time lag between the bursts provides a manner to measure the value of $\sqrt{g_{aa}}$. Unfortunately, the time lag in case of SN1987A is quite too large since the distance of order $1.5 \cdot 10^5$ ly. The observation of the same spectral line with two different cosmological red-shifts is second effect of this kind and might be erratically interpreted as the existence of two different objects on same line of sight.

5.1.4 Why some stars seem to be older than the Universe?

Red-shifts are determined by the apparent velocity of astrophysical object which is in good approximation given $v = Hr$, where H is Hubble constant which in TGD depends on space-time sheet along which photons propagate. One has $r = sinh(X)$ for hyperbolic cosmology and $r = X$ for critical cosmology, where the function X is defined by Eq. 79. For matter dominated cosmology with $g_{aa} = Ka$ and for almost flat hyperbolic cosmology with $g_{aa} = 1 - \epsilon$ one has

$$\begin{aligned} X &= 2\left[(Ka)^{1/2} - (Ka_0)^{1/2}\right] < 1 \ , \quad \text{(matter dominance)} \ , \\ X &= \sqrt{(1-\epsilon)}log(\frac{a}{a_0}) \ , \quad \text{(almost flat hyperbolic)} \ . \end{aligned} \tag{86}$$

From this it is clear that the approximation $sinh(X) \simeq X$ makes sense in case of matter dominated cosmology and the red-shifts do not differ much from those predicted by critical cosmology.

For almost flat hyperbolic cosmology and for vapor phase situation is dramatically different since red-shifts can be exponentially larger. Therefore, if most of radiation comes along matter dominated or critical space-time sheets, then the radiation coming in vapor phase or along almost flat hyperbolic space-time sheets can give rise to huge red-shifts and stars which seem to be older than the Universe. The presence of several space-time sheets means that using common value of Hubble constant one obtains entire spectrum of ages of the Universe. Same astrophysical can also give rise to several images corresponding to the photons propagating along various space-time sheets. It might be that this mechanism might be involved with the observed multiple images of stars.

5.1.5 The puzzle of several Hubble constants

Each cosmic space-time has its own Hubble constant defined as

$$H = \frac{1}{a\sqrt{g_{aa}}} \ , \tag{87}$$

where the value of the light cone proper time corresponds to the light cone proper time of observer in the sub-light cone defined by the sub-cosmology. The value of Hubble constant is smallest at almost flat space-time sheets. Photons propagating along almost flat space-time sheet or in vapor phase provide a possible solution to the puzzle of two different Hubble constants if the mass density is sufficiently large. The distances derived from type Ia super-novae give $H_0^a = 54 \pm 8 \ kms^{-1}Mpc^{-1}$ to be compared with the Hubble result $H_0^b = 80 \pm 17 \ kms^{-1}Mpc^{-1}$ [38].

The discrepancy is resolved if the measurement of the distance is correct and made using photons propagating in vapor phase or along almost flat hyperbolic space-time sheets so that H_0^a corresponds in good approximation to the Hubble constant of M^4_+, which is by a factor

$$\frac{H_0^a}{H_0^b} = \frac{H_0(M^4_+)}{H_0(X^4)} = \sqrt{g_{aa}} = \sqrt{1-\epsilon} \sim 2/3 \tag{88}$$

smaller than the Hubble constant of the space-time surface. The needed mass density $\epsilon = 5/9$ and the ratio of the propagation velocities of light differs considerably from unity. For $\epsilon = .1$ the ratio of two Hubble constants is predicted to be .95 and some other explanation for discrepancy is needed. The model for the stationary cosmology indeed suggests that the density of matter is much below the value needed to explain the Hubble discrepancy in this manner.

For instance, for the space-time outside the Kähler charged cosmic string, discussed in [D5], one has

$$g_{tt} = 1 - \frac{R^2\omega^2}{4}(1-u^2) \ \ , \ \ -1 < u(\rho) < 1).$$

The model for the galaxy formation requires $exp(4\omega R) \sim 10^3$ and this gives $\frac{\omega^2 R^2}{4} \simeq .86$ implying $\sqrt{g_{tt}} \geq .37$ so that the reduction of the local light velocity can be rather large and explain the Hubble controversy.

In fact, there are quite recent results [41], which can be interpreted as a support for the many-sheeted space-time picture with separate Hubble constant associated with each sheet. The preliminary result is that the Hubble constant determined from the nearby supernovas is larger than that determined from the faraway supernovas. The proposed interpretation is that the rate of the expansion of the Universe is increasing in the course of time. The increase could be due to the non-vanishing cosmological constant corresponding to a vacuum energy density about 40 per cent of the critical density: the origin of this vacuum energy density remains a mystery.

TGD suggests suggests that Hubble constant depends on the (p-adic) length scale associated with the space-time sheet and decreases as the length scale increases. [This could also solve the problem of the two different Hubble constants since entire spectrum of Hubble constants is predicted]. Photons from nearby supernovas have suffered a topological condensation on a smaller space-time sheet as those from faraway supernovas. Hence the Hubble constant for nearby supernovas is larger and the rate of the expansion of the Universe is found to apparently increase in the course of time.

The decrease of the Hubble constant as a function of the (p-adic) length scale characterizing a given space-time sheet would follow from the fractality of the TGD Universe implying that the mass density as a function of the p-adic length scale decreases in the long length scales. Fractality could in turn would follow from the basic hypothesis necessary to get a sensible cosmology in TGD, namely that a space-time sheet corresponding to a given p-adic length scale expands until it reaches critical size not too much larger than the p-adic length scale in question. This does not exclude the possibility that the matter topologically condensed on the space-time sheet in question continues expanding and is therefore gradually drifted to the boundaries of the space-time sheet. The presence of the large voids with galaxies on their boundaries, is consistent with this assumption. From the view point of a given space-time sheet, smaller space-time sheets behave like particles of fixed size, whose density is gradually reduced in the cosmic expansion.

5.2 Mechanism of accelerated expansion in TGD Universe

In TGD framework the most plausible identification for the accelerated periods of cosmic expansion is in terms of phase transitions increasing gravitational Planck constant. These phase transitions would in average sense provide quantum counterpart for smooth cosmic expansion. An interesting question is how the explanation for accelerated cosmic expansion in terms of the presence of negative gravitational masses of "big" cosmic strings relates with the assumption of positive cosmological constant.

5.2.1 How accelerated expansion results in standard cosmology?

The accelerated of cosmic expansion means that the deceleration parameter

$$q = -(ad^2a/ds^2)/(da/ds)^2$$

is negative. For Robertson-Walker cosmologies one has

$$H^2 \equiv (\frac{da/ds}{a})^2 = \frac{8\pi G\rho + \Lambda}{3} - K/a^2, \quad K = 0, \pm 1 \ ,$$
$$3\frac{d^2a/ds^2}{a} = \Lambda - 4\pi G(\rho + 3p) \equiv -4\pi G(1+3w)\rho \ . \quad (89)$$

It is clear that the accelerated expansion requires positive value of Λ.

The deceleration parameter can be expressed as $q = \frac{1}{2}(1+3w)(1+K/(aH)^2)$. $K =, 0, 1, -1$ tells whether the cosmology is flat, hyper-spherical, or hyperbolic. The rate for the change of Hubble constant can be expressed as $(dH/ds)/H^2 = (1+q)$ and the acceleration of cosmic expansion means $q < -1$. All particle models predict $q \geq -1$.

On basis of modified Einstein's equations written for the recent metric convention (+,-,-.-) (note that opposite signature changes the sign of the left hand side)

$$-G^{\alpha\beta} - \Lambda g^{\alpha\beta} = 8\pi G T^{\alpha\beta} \quad (90)$$

it is clear that the introduction of a positive cosmological constant could be interpreted by saying that for gravitational vacuum carries energy density equal to $\Lambda/8\pi$ and negative pressure. The negative gravitational pressure would induce the acceleration. Cosmological term at the level of field equations could be also interpreted by saying that Einstein's equations hold true in the original sense but that energy momentum tensor contains besides the density of inertial mass also a positive density of purely gravitational mass: $T \rightarrow T + \Lambda g$ so that Equivalence Principle fails. Since cosmological constant means effectively negative pressure $p = -\Lambda/8\pi$ the introduction of the cosmological constant means the effective replacement $\rho + 3p \rightarrow \rho + 3p - 2\Lambda/8\pi)$. In the so called $\Lambda - CDM$ model [63] the densities of dark energy, ordinary matter, and dark matter are assumed to sum up to critical mass density $\rho_{cr} = 3/(8\pi g_{aa} G a^2)$. The fraction of dark matter density is deduced to be $\Omega_\Lambda = .74$ from mere criticality.

5.2.2 Critical cosmology predicts accelerated expansion

In order to get clue about the mechanism of accelerated cosmic expansion in TGD framework it is useful to study the deceleration parameter for various cosmologies in TGD framework.

In standard Friedmann cosmology with non-vanishing cosmological constant one has

$$3\frac{d^2a/ds^2}{a} = \Lambda - 4\pi G(\rho + 3p) \ . \quad (91)$$

From this form it is obvious why $\Lambda > 0$ is required in order to obtain accelerating expansion.

Deceleration parameter is a purely geometric property of cosmology and defined as

$$q \equiv -a\frac{d^2a/ds^2}{(da/ds)^2} \ . \quad (92)$$

During radiation and matter dominated phases the value of q is positive. In TGD framework there are several metrics which are independent of details of dynamics.

1. String dominated cosmology

String dominated cosmology is hyperbolic cosmology and might serve as a model for very early cosmology corresponds to the metric

$$g_{aa} \equiv (ds/da)^2 = 1 - K_0 \ . \tag{93}$$

In this case one has $q = 0$. A possible interpretation is that during the primordial phase also $g \leq 1$ strings dominate and imply that stringy contribution to the gravitational mass is positive.

2. Critical cosmology

Critical cosmology with flat 3-space corresponds to

$$\begin{aligned} g_{aa} &= 1 - K \ , \\ K &\equiv \frac{K_0}{1-u^2} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{94}$$

g_{aa} has the same form also for over-critical cosmologies. Both cosmologies have finite duration. In this case q is given by

$$q = -K_0 \frac{K_0 u^2}{1-u^2-K_0} < 0 \ , \tag{95}$$

and is negative. The rate of change for Hubble constant is

$$\frac{dH/ds}{H^2} = -(1+q) \ , \tag{96}$$

so that one must have $q < -1$ in order to have acceleration. This holds true for $a > \sqrt{(1-K_0)/(1+K_0)}a_1$.

Quantum critical cosmology could be seen as a universal characteristic of quantum critical phases associated with phase transition like phenomena. No assumptions about the mechanism behind the transition are made. There is great temptation to assign this cosmology to the phase transitions increasing the size of large voids occurring during late cosmology. The observed jerk assumed to lead from de-accelerated to accelerated expansion for about 13 billion years ago might have interpretation as a transition of this kind.

3. Stationary cosmology

TGD predicts a one-parameter family of stationary cosmologies from the requirement that the density of gravitational 4-momentum is conserved. This is guaranteed if curvature scalar is extremized. These cosmologies are expected to define asymptotic cosmologies or at least characterize the stationary phases between quantum phase transitions. The metric is given by

$$\begin{aligned} g_{aa} &= \frac{1-2x}{1-x} \ , \\ x &= (\frac{a_0}{a})^{2/3} \ . \end{aligned} \tag{97}$$

The deceleration parameter

$$q = \frac{1}{3}\frac{x}{(1-2x)(1-x)} \ . \tag{98}$$

is positive so that it seems that TGD does not lead to a continual acceleration which might be regarded as tearing galaxies into pieces.

If quantum critical phases correspond to the expansion of large voids induced by the accelerated radial motion of galactic strings as they reach the boundaries of the voids, one can consider a series of phase transitions between stationary cosmologies in which the value of gravitational Planck constant and the parameter a_0 characterizing the stationary cosmology increase by some even power of two as the ruler-and-compass integer hypothesis [C9, D3] and p-adic length scale hypothesis suggests.

5.2.3 What is the mechanism causing the accelerated expansion in TGD inspired cosmology?

One can safely conclude that TGD predict accelerated cosmic expansion during critical periods and that dark energy is replaced with dark matter in TGD framework. There is also a rather clear view about detailed mechanism leading to the accelerated expansion at "microscopic" level. It is an interesting exercise to try to express this mechanism in the framework of Robertson-Walker cosmology and also try to relate the description to descriptions in terms of cosmological constant and quintessence.

1. Topologically condensed cosmic strings serve as sources of gravitational field with string tension determined by their gravitational mass whose value at the exterior space-time sheet increases by the Kähler contribution to the gravitational mass. The energy momentum tensor of a straight cosmic string with genus g is projection to the 2-dimensional Minkowski space M^2 defined by the string.

   The purely gravitational part of the energy momentum tensor is proportional to the metric g_2 of flat string wordsheet $M^2 \subset M^4$. In long enough length scales spatial and directional averaging would give $T_{gr} = -K[n^\alpha n^\beta + (g^{\alpha\beta} - n^{\alpha\beta})/3]$ with $p = -\Lambda/3$. This would give $\rho_\Lambda + 3p_\Lambda = 0$ so that no accelerating expansion would result. This is as it should be since the effect is wanted only during periods when large voids expand in a phase transition changing the parameter a_0 characterizing stationary cosmology.

2. One might argue that for stationary cosmic strings at low temperatures transverse vibrational degrees of freedom are frozen and they behave like point like particles. This leaves rigid body rotational degrees of freedom but at least for $g > 1$ big strings these degrees of freedom would be absent. Since cosmic strings are so heavy, the pressure term in the energy momentum tensor describing the transversal degrees of freedom is negligible as compared to the rest energy. This would give $\rho + 3p \rightarrow \rho + 3p - \Lambda$. Galactic strings give analogous contribution but with a positive value of Λ if one can assume that they behave like rigid bodies.

3. If the gravitational energies of big string with $g > 2$ and galactic strings with $g \leq 1$ sum up to zero to guarantee a restoration of Equivalence Principle in length scales longer than that for large void, no net effect results. During the transition periods between two stationary cosmologies the vibrational degrees of freedom of galactic strings could be excited with some probability so that their net contribution to $\rho + 3p$ is reduced meaning that the contribution of big strings would not be cancelled anymore and accelerated expansion would result.

Some summarizing remarks are in order.

1. Accelerated expansion is predicted only during periods of over-critical and critical cosmologies parameterized essentially by their duration. The microscopic description would be in terms of phase transitions increasing the size scale of large void. This phase transition is basically a quantum jump increasing gravitational Planck constant and thus the size of the large void.

p-Adic length scales are favored sizes of the large voids. A large piece of 4-D cosmological history would be replaced by a new one in this transition so that quite a dramatic event would be in question.

2. p-Adic fractality forces to ask whether there is a fractal hierarchy of time scales in which Equivalence Principle fails locally. This would predict a fractal hierarchy of large voids and phase transitions during which accelerated expansion occurs.

3. Cosmological constant can be said to be vanishing in TGD framework and the description of accelerated expansion in terms of a positive cosmological constant is not equivalent with TGD description since Λ means positive energy and negative pressure in GRT framework and negative energy in TGD framework. TGD description has some resemblance to the description in terms of quintessence [60], a hypothetical form of matter for which equation of state is of form $p = -w\rho$, $w < -1/3$, so that one has $\rho + 3p = 1 - w < 0$ and deceleration parameter can be negative. The energy density of quintessence is however positive. TGD does not predict endlessly accelerated acceleration tearing galaxies into pieces if the total purely gravitational energy of large voids is assumed to vanish so that Equivalence Principle holds above this length scale.

5.2.4 The reported cosmic jerk as an accelerated period of cosmic expansion

There is an objection against the hypothesis that cosmological constant has been gradually decreasing during the cosmic evolution. Type Ia supernovae at red shift $z \sim .45$ are fainter than expected, and the interpretation is in terms of an accelerated cosmic expansion [42]. If a period of an accelerated expansion has been preceded by a decelerated one, one would naively expect that for older supernovae from the period of decelerating expansion, say at redshifts about $z > 1$, the effect should be opposite. The team led by Adam Riess [43] has identified 16 type Ia supernovae at redshifts $z > 1.25$ and concluded that these supernovae are indeed brighter. The conclusion is that about about 5 billion years ago corresponding to $z \simeq .48$, the expansion of the Universe has suffered a cosmic jerk and transformed from a decelerated to an accelerated expansion.

The apparent dimming/brightening of supernovae at the period of accelerated/decelerated expansion the follows from the luminosity distance relation

$$\mathcal{F} = \frac{\mathcal{L}}{4\pi d_L^2} \ , \tag{99}$$

where $\mathcal{L}$ is actual luminosity and $\mathcal{F}$ measured luminosity, and from the expression for the distance d_L in flat cosmology in terms of red shift z in a flat Universe

$$\begin{aligned} d_L &= (1+z)\int_0^z \frac{du}{H(u)} \\ &= (1+z)H_0^{-1}\int_0^z exp\left[-\int_0^u du\left[1+q(u)\right]d(ln(1+u)\right]du \ , \end{aligned} \tag{100}$$

where one has

$$\begin{aligned} H(z) &= \frac{dln(a)}{ds} \ , \\ q &\equiv -\frac{d^2a/ds^2}{aH^2} = \frac{dH^{-1}}{ds} - 1 \ . \end{aligned} \tag{101}$$

In TGD framework a corresponds to the light-cone proper time and s to the proper time of Robertson-Walker cosmology. Depending on the sign of the deceleration parameter q, the distance d_L is larger or smaller and accordingly the object looks dimmer or brighter.

The natural interpretation for the jerk would be as a period of accelerated cosmic expansion due to a phase transition increasing the value of gravitational Planck constant.

5.3 Could many-sheeted cosmology explain the claimed time dependence of the fine structure constant?

There is recent evidence for the time dependence of the fine structure constant in cosmological time scales [36]. The spectroscopic observations of a number of absorption systems in the spectra of distant quasars indicate a smaller value of α in the past. The comparison of the ratios of the frequencies for relativistic atomic transitions depending non-linearly on α^2 gives the average value $\Delta\alpha/\alpha = -0.72 \pm .18 \times 10^{-5}$ in the red shift range $z = .5 - 3.5$.

On the other hand, the data about the isotopic abundances in Oklo natural reactor which operated at 1.8×10^9 years ago gives the upper bound $\Delta\alpha/\alpha \leq 10^{-7}$ [39]: this corresponds to the red shift $z = .13$. This suggests an abrupt change of the fine structure constant in the range $.13 < z_0 \leq .5$.

A further important piece of data is about type Ia super-novae in distant galaxies. These data have extended the Hubble diagram to red shifts $z \geq 1$ [40]. The data imply an accelerated expansion of the universe in the framework of standard cosmology requiring the introduction of cosmological constant and vacuum energy density of unknown origin.

The notion of the many-sheeted cosmology might explain the apparent acceleration of the cosmological expansion. The notion of the many-sheeted space-time could also explain the apparent time variation of the fine structure constant as the following arguments tend to demonstrate.

5.4 Apparent time dependence of the fine structure constant

There is recent evidence for the time dependence of the fine structure constant in cosmological time scales [36]. The spectroscopic observations of a number of absorption systems in the spectra of distant quasars indicate a smaller value of α in the past. The comparison of the ratios of the frequencies for relativistic atomic transitions depending non-linearly on α^2 gives the average value $\Delta\alpha/\alpha = -0.72 \pm .18 \times 10^{-5}$ in the red shift range $z = .5 - 3.5$.

On the other hand, the data about the isotopic abundances in Oklo natural reactor which operated at 1.8×10^9 years ago gives the upper bound $\Delta\alpha/\alpha \leq 10^{-7}$ [39]: this corresponds to the red shift $z = .13$. This suggests an abrupt change of the fine structure constant in the range $.13 < z_0 \leq .5$. More recent measurements have measured no variation [56]. Despite this it is an interesting exercise to see whether the variation might have some explanation in TGD framework.

Assume that new space-time sheets with size determined by the p-adic length scale $L(k)$ emerge at values $t \sim L(k)$ of the time coordinate during the cosmological evolution. It is also assumed that the proper description of atoms involves in an essential manner the concept of classical em field. This is indeed the case in TGD framework but not for the Bether-Salpeter equation relying on correlation functions and the abstraction of the basic features of perturbative QED.

1. The basic point is that atomic nuclei need not feed their entire electric gauge fluxes to the atomic space-time sheet, which presumably corresponds to $p \simeq 2^k$, $k = 131$ or $k = 137$, but can feed a small fraction of the electric flux also to the larger space-time sheets. The simplest assumption is that each new cosmological space-time sheet receives a constant fraction of the existing nuclear gauge charge. Stability requirement suggests that also each electron feeds a negative fraction of its electric flux to the larger space-time sheet so that an overall charge neutrality is preserved. The fraction must be negative to guarantee that the nuclear and

electronic charges effectively increase in magnitude when new larger space-time sheets emerge during the cosmological evolution. Negative fraction is favored also by the fact that the effective nuclear charge would otherwise approach zero in the sufficiently distant geometric future. The effect corresponds to an apparent renormalization of the fine structure constant having nothing to do with the ordinary QED renormalization or the renormalization of the fine structure constant suggested by the p-adic coupling constant evolution.

2. The experimental findings suggest that the distribution of the electric gauge fluxes between different space-time sheets could have changed in some abrupt manner during the period $.16 < z_0 < .5$. The lower bound follows from the fact that Oklo natural reactor data are consistent with the laboratory value of the effective fine structure constant. Assume that this abrupt change corresponds to the emergence of a new space-time sheet at $z = z_0$ taking a negative fraction of order $\epsilon \sim -10^{-5}$ of the nuclear and electronic gauge fluxes so that the effective nuclear and electronic charges increase correspondingly in magnitude. More generally, assume that this occurs for all values of cosmic time $t(k) \sim L(k)$ corresponding to p-adic length scales.

3. If the p-adic length scale L_p appears at $t = a \simeq L_p$ then p-adic length scales appear at $a(k_n) = 2^{(k_n-k_0)/2}a_{k_0}$. The effective fine structure constant is predicted to be constant inside intervals $[a(k_n), a(k_{n-1})]$. The minimum value for the increment of k_n is $\Delta k = k_n - k_{n-1} = 2$ and corresponds to a variation of a by single octave and to a pair of twin primes $k_n = k_{n-1}+2$. This predicts the constancy of the effective fine structure constant after $z = z_0$ in accordance with the experimental facts. If $z_0 = a_{now}/a_0 - 1$ corresponds to the first abrupt change in the range $.13 < z_0 < .5$ then for $\Delta k = 2$ another abrupt change would occur at $z_1 = 2z_0 + 1$, $1.26 < z_1 < 3$. If each space-time sheet receives the same amount of electric flux, one has $\Delta[log(\alpha)](z_1) \simeq 2\Delta[log(\alpha)](z_0)$, which is excluded in the range considered. For $\Delta k = 4$ the next abrupt change would correspond to $z_2 = 4z_0 + 3$: $3.52 < z_2 < 5$. Unfortunately, this value of z is slightly above the range studied in [37]. For $\Delta k = 6$ one would have $z_3 = 8z_0+7$, $8 < z_3 < 11$.

4. The negative em flux which is fraction of order $\epsilon \sim -10^{-5}$ of nuclear electromagnetic charge flowing to single space-time sheet does not lead to any inconsistencies since the number of the primary p-adic length scales between atomic length scale and cosmological length scales is only 45. Therefore the total variation between $a = a_{now} \sim 10^{10}$ years and $a = 10^7$ years (this is the range probed by the cosmic microwave background) would correspond to something like five p-adic length scales for $t = a$ and the predicted net variation in the red shift interval $.13 < z < 10^3$ would not be larger than $\Delta[log(\alpha)] \sim 10^{-4}$ if each p-adic space-time sheet receives the same amount of the electric flux.

Note that this model might be seen as a topological and microscopic version of the Bekenstein's field theory model [52] based on the assumption that fine structure constant is a slowly varying scalar field Φ having naturally the needed linear coupling to the Maxwell action. In [39] it was suggested that Φ could correspond to the so called quintessence field believed to give rise to cosmological vacuum energy and that Bekenstein's model could explain the observed variation of the fine structure constant. Note that in many-sheeted cosmology charge conservation is not lost although the effective fine structure constant depends on cosmological time.

5.5 The problem of fermion families

The generation-genus correspondence implies that the number of the particle families is apparently infinite. The arguments developed in the second part of the book however suggest that $g > 2$ particle families have masses of order $m_0 \sim 10^{-4}m_{Pl}$ except possibly at the very early stages of the cosmology in the vapor phase. One should somehow understand how the effective number of particle families manages to be finite and whether very early TGD inspired cosmology allows infinite number of light particle families. In the following I shall consider the possibility that the existence of the vapor phase might provide solutions to this problem.

Without additional constraints TGD predicts infinite number of particles families (both bosonic and fermionic) since each boundary topology characterized by the handle number corresponds to a separate elementary particle. On the other hand, GRT based cosmology poses stringent bounds on the number of the fermion families. The number of the light fermion families is generally believed to be not larger than 3 or 4. In TGD the problem is even more acute if all elementary particles are massless in the vapor phase.

The original proposal for the solution of the problem was based on the following arguments.

1. The masses $M(g)$ of the topologically condensed elementary fermions increase as a function of the genus of the boundary component. In particular, higher genus neutrinos are (very) massive. The properties of the elementary particle vacuum functionals suggest that condensed $g > 2$ particle families have masses of order CP_2 mass.

2. Massive condensed fermions with mass $M(g)$ begin to decay at temperature $T \simeq M(g)$. If $M(g)$ increases sufficiently rapidly the number $N(a)$ of the effectively massless fermions in the topological condensate is always finite due to the decay of the massive fermions. The temperature equals to the critical temperature $T_H \sim 1/R$ before $a = a_F \sim 10^{-11}$ sec. If the masses of the higher fermion families are larger than T_H, their contribution to the mass density is exponentially suppressed and they are effectively absent from cosmology. Thus the number of fermion families is effectively finite and equal to three if the argument based on elementary particle vacuum functionals holds true.

3. Massless fermions could be present in vapor phase but their fraction of energy density is presumably negligible since vapor phase is expected to be in zero temperature.

It has turned out [F1] that under very general conditions the number of fermion families is three. The idea is that the property of being fermion has some space-time correlate. There are reasons to believe that this correlate is Z_2 conformal symmetry for the corresponding partonic 2-surfaces. This symmetry implies that fermionic elementary particle vacuum functionals vanish identically for $g > 2$. This holds true also for gauge bosons which can be regarded as fermion anti-fermion pairs associated with the light-like throats of wormhole contact. The argument is represented in detail in [F1].

6 Simulating Big Bang in laboratory

Ultra-high energy collisions of heavy nuclei at Relativistic Heavy Ion Collider (RHIC) can create so high temperatures that there are hopes of simulating Big Bang in laboratory. The experiment with PHOBOS detector [64] probed the nature of the strong nuclear force by smashing two Gold atoms together at ultrahigh energies. The analysis of the experimental data has been carried out by Prof. Manly and his collaborators at RHIC in Brookhaven, NY [65]. The surprise was that the hydrodynamical flow for non-head-on collisions did not possess the expected longitudinal boost invariance.

This finding stimulates in TGD framework the idea that something much deeper might be involved.

1. The quantum criticality of the TGD inspired very early cosmology predicts the flatness of 3-space as do also inflationary cosmologies. The TGD inspired cosmology is 'silent whisper

amplified to big bang' since the matter gradually topologically condenses from decaying cosmic string to the space-time sheet representing the cosmology. This suggests that one could model also the evolution of the quark-gluon plasma in an analogous manner. Now the matter condensing to the quark-gluon plasma space-time sheet would flow from other space-time sheets. The evolution of the quark-gluon plasma would very literally look like the very early critical cosmology.

2. What is so remarkable is that critical cosmology is not a small perturbation of the empty cosmology represented by the future light cone. By perturbing this cosmology so that the spherical symmetry is broken, it might possible to understand qualitatively the findings of [65]. Even more, the breaking of the spherical symmetry in the collision could be understood as a strong gravitational effect on distances transforming the spherical shape of the plasma ball to a non–spherical shape without affecting the spherical shape of its M^4_+ projection.

3. The model seems to work and predicts strong gravitational effects in elementary particle length scales so that TGD based gravitational physics would differ dramatically from that predicted by the competing theories. Standard cosmology cannot produce these effects without a large breaking of the cherished Lorentz and rotational symmetries forming the basis of elementary particle physics. Thus the PHOBOS experiment gives direct support for the view that Poincare symmetry is symmetry of the imbedding space rather than that of the space-time.

4. This picture was completed a couple of years later by the progress made in hadronic mass calculations [F4]. It has already earlier been clear that quarks are responsible only for a small part of the mass of baryons (170 GeV in case of nucleons). The assumption that hadronic $k = 107$ space-time sheet carries a many-particle state of super-canonical particles with vanishing electro-weak quantum numbers (meaning darkness in the strongest sense of the word) allows a model of hadrons predicting their masses with accuracy better than one per cent. The large value of Kähler coupling strength $\alpha_K = \alpha_s = 1/4$ for ordinary value of Planck constant motivates the hypothesis that a transition to large $\hbar$ phase occurs: $\hbar = 26 \times \hbar_0$ would leave the value of α_K for gauge boson field bodies ($\alpha_K = 1/104$) invariant [C5]. $J = 2$ excitations have identification as strong gravitons. In this framework color glass condensate can be identified as a state formed when the hadronic space-time sheets of colliding hadrons fuse to single long stringy object and collision energy is transformed to super-canonical hadrons.

6.1 Experimental arrangement and findings

6.1.1 Heuristic description of the findings

In the experiments using PHOBOS detector ultrahigh energy Au+Au collisions at center of mass energy for which nucleon-nucleon center of mass energy is $\sqrt{s_{NN}} = 130$ GeV, were studied [64].

1. In the analyzed collisions the Au nuclei did not collide quite head-on. In classical picture the collision region, where quark gluon plasma is created, can be modelled as the intersection of two colliding balls, and its intersection with plane orthogonal to the colliding beams going through the center of mass of the system is defined by two pieces of circles, whose intersection points are sharp tips. Thus rotational symmetry is broken for the initial state in this picture.

2. The particles in quark-gluon plasma can be compared to a persons in a crowded room trying to get out. The particles collide many times with the particles of the quark gluon plasma before reaching the surface of the plasma. The distance $d(z, \phi)$ from the point $(z, 0)$ at the beam axis to the point $(0, \phi)$ at the plasma surface depends on ϕ. Obviously, the distance is

longest to the tips $\phi = \pm\pi/2$ and shortest to the points $\phi = 0, \phi = \phi$ of the surface at the sides of the collision region. The time $\tau(z, \phi)$ spent by a particle to the travel to the plasma surface should be a monotonically increasing function $f(d)$ of d:

$$\tau(z, \phi) = f(d(z, \phi)) \ .$$

For instance, for diffusion one would have $\tau \propto d^2$ and $\tau \propto d$ for a pure drift.

3. What was observed that for $z = 0$ the difference

$$\Delta\tau = \tau(z = 0, \pi/2) - \tau(z = 0, 0)$$

was indeed non-vanishing but that for larger values of z the difference tended to zero. Since the variation of z correspond that for the rapidity variable y for a given particle energy, this means that particle distributions depend on rapidity which means a breaking of the longitudinal boost invariance assumed in hydrodynamical models of the plasma. It was also found that the difference vanishes for large values of y: this finding is also important for what follows.

6.1.2 A more detailed description

Consider now the situation in a more quantitative manner.

1. Let z-axis be in the direction of the beam and ϕ the angle coordinate in the plane E^2 orthogonal to the beam. The kinematical variables are the rapidity of the detected particle defined as $y = log[E+p_z)/(E-p_z)]/2$ (E and p_z denote energy and longitudinal momentum), Feynman scaling variable $x_F \simeq 2E/\sqrt{s}$, and transversal momentum p_T.

2. By quantum-classical correspondence, one can translate the components of momentum to space-time coordinates since classically one has $x^\mu = p^\mu a/m$. Here a is proper time for a future light cone, whose tip defines the point where the quark gluon plasma begins to be generated, and $v^\mu = p^\mu/m$ is the four-velocity of the particle. Momentum space is thus mapped to an $a = constant$ hyperboloid of the future light cone for each value of a.

   In this correspondence the rapidity variable y is mapped to $y = log[(t+z)/(t-z)]$, $|z| \leq t$ and non–vanishing values for y correspond to particles which emerge, not from the collision point defining the origin of the plane E^2, but from a point above or below E^2. $|z| \leq t$ tells the coordinate along the beam direction for the vertex, where the particle was created. The limit $y \to 0$ corresponds to the limit $a \to \infty$ and the limit $y \to \pm\infty$ to $a \to 0$ (light cone boundary).

3. Quark-parton models predict at low energies an exponential cutoff in transverse momentum p_T; Feynman scaling $dN/dx_F = f(x_F)$ independent of s; and longitudinal boost invariance, that is rapidity plateau meaning that the distributions of particles do not depend on y. In the space-time picture this means that the space-time is effectively two-dimensional and that particle distributions are Lorentz invariant: string like space-time sheets provide a possible geometric description of this situation.

4. In the case of an ideal quark-gluon plasma, the system completely forgets that it was created in a collision and particle distributions do not contain any information about the beam direction. In a head-on collision there is a full rotational symmetry and even Lorentz invariance so that transverse momentum cutoff disappears. Rapidity plateau is predicted in all directions.

5. The collisions studied were not quite head-on collisions and were characterized by an impact parameter vector with length b and direction angle ψ_2 in the plane E^2. The particle distribution at the boundary of the plane E^2 was studied as a function of the angle coordinate $\phi - \psi_2$ and rapidity y which corresponds for given energy distance to a definite point of beam axis.

The hydrodynamical view about the situation looks like follows.

1. The particle distributions $N(p^\mu)$ as function of momentum components are mapped to space-time distributions $N(x^\mu, a)$ of particles. This leads to the idea that one could model the situation using Robertson-Walker type cosmology. Co-moving Lorentz invariant particle currents depending on the cosmic time only would correspond in this picture to Lorentz invariant momentum distributions.

2. Hydrodynamical models assign to the particle distribution $d^2N/dyd\phi$ a hydrodynamical flow characterized by four-velocity $v^\mu(y, \phi)$ for each value of the rapidity variable y. Longitudinal boost invariance predicting rapidity plateau states that the hydrodynamical flow does not depend on y at all. Because of the breaking of the rotational symmetry in the plane orthogonal to the beam, the hydrodynamical flow v depends on the angle coordinate $\phi - \psi_2$. It is possible to Fourier analyze this dependence and the second Fourier coefficient v_2 of $cos(2(\phi - \psi_2)$ in the expansion

$$\frac{dN}{d\phi} \simeq 1 + \sum_n v_n cos(n(\phi - \psi_2)) \quad (102)$$

   was analyzed in [65].

3. It was found that the Fourier component v_2 depends on rapidity y, which means a breaking of the longitudinal boost invariance. v_2 also vanishes for large values of y. If this is true for all Fourier coefficients v_n, the situation becomes effectively Lorentz invariant for large values of y since one has $v(y, \phi) \rightarrow 1$.

   Large values of y correspond to small values of a and to the initial moment of big bang in cosmological analogy. Hence the finding could be interpreted as a cosmological Lorentz invariance inside the light cone cosmology emerging from the collision point. Small values of y in turn correspond to large values of a so that the breaking of the spherical symmetry of the cosmology should be manifest only at $a \rightarrow \infty$ limit. These observations suggest a radical re-consideration of what happens in the collision: the breaking of the spherical symmetry would not be a property of the initial state but of the final state.

6.2 TGD based model for the quark-gluon plasma

Consider now the general assumptions the TGD based model for the quark gluon plasma region in the approximation that spherical symmetry is not broken.

1. Quantum-classical correspondence supports the mapping of the momentum space of a particle to a hyperboloid of future light cone. Thus the symmetries of the particle distributions with respect to momentum variables correspond directly to space-time symmetries.

2. The M^4_+ projection of a Robertson-Walker cosmology imbedded to $H = M^4_+ \times CP_2$ is future light cone. Hence it is natural to model the hydrodynamical flow as a mini-cosmology. Even more, one can assume that the collision quite literally creates a space-time sheet which

locally obeys Robertson-Walker type cosmology. This assumption is sensible in many-sheeted space-time and conforms with the fractality of TGD inspired cosmology (cosmologies inside cosmologies).

3. If the space-time sheet containing the quark-gluon plasma is gradually filled with matter, one can quite well consider the possibility that the breaking of the spherical symmetry develops gradually, as suggested by the finding $v_2 \rightarrow 1$ for large values of $|y|$ (small values of a). To achieve Lorentz invariance at the limit $a \rightarrow 0$, one must assume that the expanding region corresponds to $r = constant$ "coordinate ball" in Robertson-Walker cosmology, and that the breaking of the spherical symmetry for the induced metric leads for large values of a to a situation described as a "not head-on collision".

4. Critical cosmology is by definition unstable, and one can model the Au+Au collision as a perturbation of the critical cosmology breaking the spherical symmetry. The shape of $r = constant$ sphere defined by the induced metric is changed by strong gravitational interactions such that it corresponds to the shape for the intersection of the colliding nuclei. One can view the collision as a spontaneous symmetry breaking process in which a critical quark-gluon plasma cosmology develops a quantum fluctuation leading to a situation described in terms of impact parameter. This kind of modelling is not natural for a hyperbolic cosmology, which is a small perturbation of the empty M^4_+ cosmology.

6.2.1 The imbedding of the critical cosmology

Any Robertson-Walker cosmology can be imbedded as a space-time sheet, whose M^4_+ projection is future light cone. The line element is

$$ds^2 = f(a)da^2 - a^2(K(r)dr^2 + r^2 d\Omega^2) \ . \tag{103}$$

Here a is the scaling factor of the cosmology and for the imbedding as surface corresponds to the future light cone proper time.

This light cone has its tip at the point, where the formation of quark gluon plasma starts. (θ, ϕ) are the spherical coordinates and appear in $d\Omega^2$ defining the line element of the unit sphere. a and r are related to the spherical Minkowski coordinates (m^0, r_M, θ, ϕ) by $(a = \sqrt{(m^0)^2 - r_M^2}, r = r_M/a)$. If hyperbolic cosmology is in question, the function $K(r)$ is given by $K(r) = 1/(1 + r^2)$. For the critical cosmology 3-space is flat and one has $K(r) = 1$.

1. The critical cosmologies imbeddable to $H = M^4_+ \times CP_2$ are unique apart from a single parameter defining the duration of this cosmology. Eventually the critical cosmology must transform to a hyperbolic cosmology. Critical cosmology breaks Lorentz symmetry at space-time level since Lorentz group is replaced by the group of rotations and translations acting as symmetries of the flat Euclidian space.

2. Critical cosmology replaces Big Bang with a silent whisper amplified to a big but not infinitely big bang. The silent whisper aspect makes the cosmology ideal for the space-time sheet associated with the quark gluon plasma: the interpretation is that the quark gluon plasma is gradually transferred to the plasma space-time sheet from the other space-time sheets. In the real cosmology the condensing matter corresponds to the decay products of cosmic string in 'vapor phase'. The density of the quark gluon plasma cannot increase without limit and after some critical period the transition to a hyperbolic cosmology occurs. This transition could, but need not, correspond to the hadronization.

3. The imbedding of the critical cosmology to $M^4_+ \times S^2$ is given by

$$sin(\Theta) = \frac{a}{a_m} ,$$
$$\Phi = g(r) . \quad (104)$$

Here Θ and Φ denote the spherical coordinates of the geodesic sphere S^2 of CP_2. One has

$$f(a) = 1 - \frac{R^2k^2}{(1-(a/a_m)^2)} ,$$
$$(\partial_r\Phi)^2 = \frac{a_m^2}{R^2} \times \frac{r^2}{1+r^2} . \quad (105)$$

Here R denotes the radius of S^2. From the expression for the gradient of Φ it is clear that gravitational effects are very strong. The imbedding becomes singular for $a = a_m$. The transition to a hyperbolic cosmology must occur before this.

This model for the quark-gluon plasma would predict Lorentz symmetry and $v = 1$ (and $v_n = 0$) corresponding to head-on collision so that it is not a realistic model.

6.2.2 TGD based model for the quark-gluon plasma without breaking of spherical symmetry

There is a highly unique deformation of the critical cosmology transforming metric spheres to highly non–spherical structures purely gravitationally. The deformation can be characterized by the following formula

$$sin^2(\Theta) = (\frac{a}{a_m})^2 \times (1 + \Delta(a,\theta,\phi)^2) . \quad (106)$$

1. This induces deformation of the g_{rr} component of the induced metric given by

$$g_{rr} = -a^2\left[1 + \Delta^2(a,\theta,\phi)\frac{r^2}{1+r^2}\right] . \quad (107)$$

   Remarkably, g_{rr} does not depend at all on CP_2 size and the parameter a_m determining the duration of the critical cosmology. The disappearance of the dimensional parameters can be understood to reflect the criticality. Thus a strong gravitational effect independent of the gravitational constant (proportional to R^2) results. This implies that the expanding plasma space-time sheet having sphere as M^4_+ projection differs radically from sphere in the induced metric for large values of a. Thus one can understand why the parameter v_2 is non-vanishing for small values of the rapidity y.

2. The line element contains also the components g_{ij}, $i,j \in \{a,\theta,\phi\}$. These components are proportional to the factor

$$\frac{1}{1-(a/a_m)^2(1+\Delta^2)} , \quad (108)$$

which diverges for

$$a_m(\theta,\phi) = \frac{a_m}{\sqrt{1+\Delta^2}} . \quad (109)$$

Presumably quark-gluon plasma phase begins to hadronize first at the points of the plasma surface for which $\Delta(\theta,\phi)$ is maximum, that is at the tips of the intersection region of the colliding nuclei. A phase transition producing string like objects is one possible space-time description of the process.

6.3 Further experimental findings and theoretical ideas

The interaction between experiment and theory is pure magic. Although experimenter and theorist are often working without any direct interaction (as in case of TGD), I have the strong feeling that this disjointness is only apparent and there is higher organizing intellect behind this coherence. Again and again it has turned out that just few experimental findings allow to organize separate and loosely related physical ideas to a consistent scheme. The physics done in RHIC has played completely unique role in this respect.

6.3.1 Super-canonical matter as the TGD counterpart of CGC?

The model discussed above explained the strange breaking of longitudinal Lorentz invariance in terms of a hadronic mini bang cosmology. The next twist in the story was the shocking finding, compared to Columbus's discovery of America, was that, rather than behaving as a dilute gas, the plasma behaved like a liquid with strong correlations between partons, and having density 30-50 times higher than predicted by QCD calculations [54]. When I learned about these findings towards the end of 2004, I proposed how TGD might explain them in terms of what I called conformal confinement [F2]. This idea - although not wrong for any obvious reason - did not however have any obvious implications. After the progress made in p-adic mass calculations of hadrons leading to highly successful model for both hadron and meson masses [F4], the idea was replaced with the hypothesis that the condensate in question is Bose-Einstein condensate like state of super-canonical particles formed when the hadronic space-time sheets of colliding nucleons fuse together to form a long string like object.

6.3.2 Fireballs behaving like black hole like objects

The latest discovery in RHIC is that fireball, which lasts a mere 10^{-23} seconds, can be detected because it absorbs jets of particles produced by the collision [66]. The association with the notion black hole is unavoidable and there indeed exists a rather esoteric M-theory inspired model "The RHIC fireball as a dual black hole" by Hortiu Nastase [68] for the strange findings.

The Physics Today article [67] "What Have We Learned From the Relativistic Heavy Ion Collider?" gives a nice account about experimental findings. Extremely high collision energies are in question: Gold nuclei contain energy of about 100 GeV per nucleon: 100 times proton mass. The expectation was that a large volume of thermalized Quark-Gluon Plasma (QCP) is formed in which partons lose rapidly their transverse momentum. The great surprise was the suppression of high transverse momentum collisions suggesting that in this phase strong collective interactions are present. This has inspired the proposal that quark gluon plasma is preceded by liquid like phase which has been christened as Color Glass Condensate (CGC) thought to contain Bose-Einstein condensate of gluons.

6.3.3 The theoretical ideas relating CGC to gravitational interactions

Color glass condensate relates naturally to several gravitation related theoretical ideas discovered during the last year.

1. Classical gravitation and color confinement

Just some time ago it became clear that strong classical gravitation might play a key role in the understanding of color confinement [E2]. Whether the situation looks confinement or asymptotic freedom would be in the eyes of beholder: one example of dualities filling TGD Universe. If one looks the situation at the hadronic space-time sheet one has asymptotic freedom, particles move essentially like free massless particles. But, and this is absolutely essential, in the induced metric of hadronic space-time sheet. This metric represents classical gravitational field becoming extremely strong near hadronic boundary. From the point of view of outsider, the motion of quarks slows down to rest when they approach hadronic boundary: confinement. The distance to hadron surface is infinite or at least very large since the induced metric becomes singular at the light-like boundary! Also hadronic time ceases to run near the boundary and finite hadronic time corresponds to infinite time of observer. When you look from outside you find that this light-like 3-surface is just static surface like a black hole horizon which is also a light-like 3-surface. Hence confinement.

2. Dark matter in TGD

The evidence for hadronic black hole like structures is especially fascinating. In TGD Universe dark matter can be (not always) ordinary matter at larger space-time sheets in particular magnetic flux tubes. The mere fact that the particles are at larger space-time sheets might make them more or less invisible.

Matter can be however dark in much stronger sense, should I use the word "black"! The findings suggesting that planetary orbits obey Bohr rules with a gigantic Planck constant [71, D7] would suggest quantum coherence of dark matter even in astrophysical length scales and this raises the fascinating possibility that Planck constant is dynamical so that fine structure constant for these charged coherent states would be proportional to $1/\hbar_{gr}$ and extremely small: hence darkness. This quantization saves from black hole collapse just as the quantization of hydrogen atom saves from the infrared catastrophe.

The obvious questions are following. Could black hole like objects/magnetic flux tubes/cosmic strings consist of quantum coherent dark matter? Does this dark matter consist dominantly from hadronic space-time sheets which have fused together and contain super-canonical bosons and their super-partners (with quantum numbers of right handed neutrino) having therefore no electro-weak interactions.

Since $\alpha_K = \alpha_s = 1/4$ would indeed justify large value of Planck constant, $\hbar = 26\hbar_0$ would leave α_K unchanged and predicts that the size of the hadronic space-time sheet is that of a large nucleus. The hadronic string tension would be predicted correctly and strong gravitation would correspond to the exchange of super-canonical $J = 2$ quanta.

This overall view would be of enormous importance even for the understanding of living matter since dark matter at magnetic flux tubes would be responsible for the quantum control of the ordinary matter. Note however that TGD based quantum model for living matter involves also dark variants of ordinary elementary particles.

From outside non-stringy TGD analogs of black holes would look just like ordinary black holes but the interior metric would be of course different from the usual one since matter would not be collapsed to a point.

Dark matter option cannot be realized in a purely hadronic system at RHIC energies since the product GM_1M_2 characterizing the interaction strength of two masses must be larger than unity ($\hbar = c = 1$) for the phase transition increasing Planck constant to occur. Hence the collision energy should be above Planck mass for the phase transition to occur if gravitational interactions are responsible for the transition.

The hypothesis is however much more general and states that the system does its best to stay perturbative by increasing its Planck constant in discrete steps and applies thus also in the case of color interactions and governs the phase transition to the TGD counterpart of non-perturbative QCD. Criterion would be roughly $\alpha_s Q_s^2 > 1$ for two color charges of opposite sign. Hadronic string picture would suggests that the criterion is equivalent to the generalization of the gravitational criterion to its strong gravity analog $nL_p^2M^2 > 1$, where L_p is the p-adic length scale characterizing color magnetic energy density (hadronic string tension) and M is the mass of the color magnetic flux tube and n is a numerical constant. Presumably L_p, $p = M_107 = 2^{107} - 1$, is the p-adic length scale since Mersenne prime M_{107} labels the space-time sheet at which partons feed their color gauge fluxes. The temperature during this phase could correspond to Hagedorn temperature (for the history and various interpretations of Hagedorn temperature see the CERN Courier article [69]) for strings and is determined by string tension and would naturally correspond also to the temperature during the critical phase determined by its duration as well as corresponding black-hole temperature. This temperature is expected to be somewhat higher than hadronization temperature found to be about $\simeq 176$ MeV. The density of inertial mass would be maximal during this phase as also the density of gravitational mass during the critical phase.

Lepto-hadron physics [F7], one of the predictions of TGD, is one instance of a similar situation. In this case electromagnetic interaction strength defined in an analogous manner becomes larger than unity in heavy ion collisions just above the Coulomb wall and leads to the appearance of mysterious states having a natural interpretation in terms of lepto-pion condensate. Lepto-pions are pairs of color octet excitations of electron and positron.

One can ask whether the Bose-Einstein condensed gluons at color magnetic flux tubes possess complex super-canonical conformal weights and whether conformal confinement could be responsible for the particle like behavior of CGC. An equally interesting question is whether ordinary liquid flow could involve Bose-Einstein condensates of particles which are not "conformal singlets".

3. Description of collisions using analogy with black holes

The following view about RHIC events represents my immediate reaction to the latest RHIC news in terms of black-hole physics instead of notions related to big bang. Since black hole collapse is roughly time reversal of big bang, the description is complementary to the earliest one.

In TGD context one can ask whether the fireballs possibly detected in RHIC are produced when a portion of quark-gluon plasma in the collision region formed by to Gold nuclei separates from hadronic space-time sheets which in turn fuse to form a larger space-time sheet separated from the remaining collision region by a light-like 3-D surface (I have used to speak about light-like causal determinants) mathematically completely analogous to a black hole horizon. This larger space-time sheet would contain color glass condensate of super-canonical gluons formed from the collision energy. A formation of an analog of black hole would indeed be in question.

The valence quarks forming structures connected by color bonds would in the first step of the collision separate from their hadronic space-time sheets which fuse together to form color glass condensate. Similar process has been observed experimentally in the collisions demonstrating the experimental reality of Pomeron, a color singlet state having no Regge trajectory [55] and identifiable as a structure formed by valence quarks connected by color bonds. In the collision it temporarily separates from the hadronic space-time sheet. Later the Pomeron and the new mesonic and baryonic Pomerons created in the collision suffer a topological condensation to the color glass condensate: this process would be analogous to a process in which black hole sucks matter from environment.

Of course, the relationship between mass and radius would be completely different with gravitational constant presumably replacement by the square of appropriate p-adic length scale presumably of order pion Compton length: this is very natural if TGD counterparts of black-holes are formed by color magnetic flux tubes. This gravitational constant expressible in terms of hadronic string tension of .9 GeV^2 predicted correctly by super-canonical picture would characterize the strong gravitational interaction assignable to super-canonical $J = 2$ gravitons. I have long time ago in the context of p-adic mass calculations formulated quantitatively the notion of elementary particle black hole analogy making the notion of elementary particle horizon and generalization of Hawking-Bekenstein law [E5].

The size L of the "hadronic black hole" would be relatively large using protonic Compton radius as a unit of length. For $hbar = 26\hbar_0$ the size would be $26 \times L(107) = 46$ fm,and correspond to a size of a heavy nucleus. This large size would fit nicely with the idea about nuclear sized color glass condensate. The density of partons (possibly gluons) would be very high and large fraction of them would have been materialized from the brehmstrahlung produced by the de-accelerating nuclei. Partons would be gravitationally confined inside this region. The interactions of partons or conformal confinement would lead to a generation of a liquid like dense phase and a rapid thermalization would occur. The collisions of partons producing high transverse momentum partons occurring inside this region would yield no detectable high p_T jets since the matter coming out from this region would be somewhat like a thermal radiation from an evaporating black hole identified as a highly entangled hadronic string in Hagedorn temperature. This space-time sheet would expand and cool down to QQP and crystallize into hadrons.

4. Quantitative comparison with experimental data

Consider now a quantitative comparison of the model with experimental data. The estimated freeze-out temperature of quark gluon plasma is $T_f \simeq 175.76$ MeV [67, 68], not far from the total contribution of quarks to the mass of nucleon, which is 170 MeV [F4]. Hagedorn temperature identified as black-hole temperature should be higher than this temperature. The experimental estimate for the hadronic Hagedorn temperature from the transversal momentum distribution of baryons is $\simeq 160$ MeV. On the other hand, according to the estimates of hep-ph/0006020 the values of Hagedorn temperatures for mesons and baryons are $T_H(M) = 195$ MeV and $T_H(B) = 141$ MeV respectively.

D-dimensional bosonic string model for hadrons gives for the mesonic Hagedorn temperature the expression [69]

$$T_H = \frac{\sqrt{6}}{2\pi(D-2)\alpha'} \ , \tag{110}$$

For a string in $D = 4$-dimensional space-time and for the value $\alpha' \sim 1\ GeV^{-2}$ of Regge slope, this would give $T_H = 195$ MeV, which is slightly larger than the freezing out temperature as it indeed should be, and in an excellent agreement with the experimental value of [70]. It deserves to be noticed that in the model for fireball as a dual 10-D black-hole the rough estimate for the temperature of color glass condensate becomes too low by a factor 1/8 [68]. In light of this I would not yet rush to conclude that the fireball is actually a 10-dimensional black hole.

Note that the baryonic Hagedorn temperature is smaller than mesonic one by a factor of about $\sqrt{2}$. According to [70] this could be qualitatively understood from the fact that the number of degrees of freedom is larger so that the effective value of D in the mesonic formula is larger. $D_{eff} = 6$ would give $T_H = 138$ MeV to be compared with $T_H(B) = 141$ MeV. On the other hand, TGD based model for hadronic masses [F4] assumes that quarks feed their color fluxes to $k = 107$ space-time sheets. For mesons there are two color flux tubes and for baryons three. Using the same logic as in [70], one would have $D_{eff}(B)/D_{eff}(M) = 3/2$. This predicts $T_H(B) = 159$ MeV to be compared with 160 MeV deduced from the distribution of transversal momenta in p-p collisions.

6.4 Are ordinary black-holes replaced with super-canonical black-holes in TGD Universe?

Some variants of super string model predict the production of small black-holes at LHC. I have never taken this idea seriously but in a well-defined sense TGD predicts black-holes associated with super-canonical gravitons with strong gravitational constant defined by the hadronic string tension. The proposal is that super-canonical black-holes have been already seen in Hera, RHIC, and the strange cosmic ray events.

Baryonic super-canonical black-holes of the ordinary M_{107} hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their M_{89} counterparts would be 512 times higher, about 478 GeV. "Ionization energy" for Pomeron, the structure formed by valence quarks connected by color bonds separating from the space-time sheet of super-canonical black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for M_{89} proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of 5×10^{10} GeV are baryons, which have lost their valence quarks in a collision with hadron and therefore have no interactions with the microwave background so that they are able to propagate through long distances.

In neutron stars the hadronic space-time sheets could form a gigantic super-canonical black-hole and ordinary black-holes would be naturally replaced with super-canonical black-holes in TGD framework (only a small part of black-hole interior metric is representable as an induced metric). This obviously means a profound difference between TGD and string models.

1. Hawking-Bekenstein black-hole entropy would be replaced with its p-adic counterpart given by

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) \ , \tag{111}$$

where $m(CP_2)$ is CP_2 mass, which is roughly 10^{-4} times Planck mass. M is the contribution of p-adic thermodynamics to the mass. This contribution is extremely small for gauge bosons but for fermions and super-canonical particles it gives the entire mass.

2. If p-adic length scale hypothesis $p \simeq 2^k$ holds true, one obtains

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2, \tag{112}$$

$m(CP_2) = \hbar/R$, R the "radius" of CP_2, corresponds to the standard value of $\hbar_0$ for all values of $\hbar$.

3. Hawking-Bekenstein area law gives in the case of Schwartschild black-hole

$$S = \frac{A}{4G} \times \hbar = \pi G M^2 \times \hbar \ . \tag{113}$$

For the p-adic variant of the law Planck mass is replaced with CP_2 mass and $klog(2) \simeq log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if

k is prime and wormhole throats have M^4 radius given by p-adic length scale $L_k = \sqrt{k}R$ which is exponentially smaller than L_p. For macroscopic super-canonical black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [D4] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses M and m [D7] reads as

$$\hbar_{gr} = \frac{GMm}{v_0}\hbar_0 \ .$$

   $v_0 = 2^{-11}$ is the preferred value of v_0. One could argue that the value of gravitational Planck constant is such that the Compton length $\hbar_{gr}/M$ of the black-hole equals to its Schwartshild radius. This would give

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \quad v_0 = 1/2 \ . \qquad (114)$$

   The requirement that $\hbar_{gr}$ is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole [D7]. Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

5. The gravitational collapse of a star would correspond to a process in which the initial value of v_0 , say $v_0 = 2^{-11}$, increases in a stepwise manner to some value $v_0 \leq 1/2$. For a supernova with solar mass with radius of 9 km the final value of v_0 would be $v_0 = 1/6$. The star could have an onion like structure with largest values of v_0 at the core as suggested by the model of planetary system. Powers of two would be favored values of v_0. If the formula holds true also for Sun one obtains $1/v_0 = 3 \times 17 \times 2^{13}$ with 10 per cent error.

6. Black-hole evaporation could be seen as means for the super-canonical black-hole to get rid of its electro-weak charges and fermion numbers (except right handed neutrino number) as the antiparticles of the emitted particles annihilate with the particles inside super-canonical black-hole. This kind of minimally interacting state is a natural final state of star. Ideal super-canonical black-hole would have only angular momentum and right handed neutrino number.

7. In TGD light-like partonic 3-surfaces are the fundamental objects and space-time interior defines only the classical correlates of quantum physics. The space-time sheet containing the highly entangled cosmic string might be separated from environment by a wormhole contact with size of black-hole horizon.

   This looks the most plausible option but one can of course ask whether the large partonic 3-surface defining the horizon of the black-hole actually contains all super-canonical particles so that super-canonical black-hole would be single gigantic super-canonical parton. The interior of super-canonical black-hole would be a space-like region of space-time, perhaps resulting as a large deformation of CP_2 type vacuum extremal. Black-hole sized wormhole contact would define a gauge boson like variant of the black-hole connecting two space-time sheets and getting its mass through Higgs mechanism. A good guess is that these states are extremely light.

6.5 Conclusions

The model for quark-gluon plasma in terms of valence quark space-time sheets separated from hadronic space-time sheets forming a color glass condensate relies on quantum criticality and implies gravitation like effects due to the presence of super-canonical strong gravitons. At space-time level the change of the distances due to strong gravitation affects the metric so that the breaking of spherical symmetry is caused by gravitational interaction. TGD encourages to think that this mechanism is quite generally at work in the collisions of nuclei. One must take seriously the possibility that strong gravitation is present also in longer length scales (say biological), in particular in processes in which new space-time sheets are generated. Critical cosmology might provide a universal model for the emergence of a new space-time sheet.

The model supports TGD based early cosmology and quantum criticality. In standard physics framework the cosmology in question is not sensible since it would predict a large breaking of the Lorentz invariance, and would mean the breakdown of the entire conceptual framework underlying elementary particle physics. In TGD framework Lorentz invariance is not lost at the level of imbedding space, and the experiments provide support for the view about space-time as a surface and for the notion of many-sheeted space-time.

The attempts to understand later strange events reported by RHIC have led to a dramatic increase of understanding of TGD and allow to fuse together separate threads of TGD.

1. The description of RHIC events in terms of the formation of hadronic black hole and its evaporation seems to be also possible and essentially identical with description as a mini bang.

2. It took some time to realize that scaled down TGD inspired cosmology as a model for quark gluon plasma predicts a new phase identifiable as color glass condensate and still a couple of years to realize the proper interpretation of it in terms of super-canonical bosons having no counterpart in QCD framework.

3. Also dark matter could be identified as a macroscopic quantum phase in which individual particles have complex conformal weights. This phase could be even responsible for the properties of living matter. There is also a connection with the dramatic findings suggesting that Planck constant for dark matter has a gigantic value.

4. Black holes and their scaled counterparts would not be merciless information destroyers in TGD Universe. The entanglement of particles possessing different conformal weights to give states with a vanishing net conformal weight and having particle like integrity would make black hole like states ideal candidates for quantum computer like systems. One could even imagine that the galactic black hole is a highly tangled cosmic string in Hagedorn temperature performing quantum computations the complexity of which is totally out of reach of human intellect! Indeed, TGD inspired consciousness predicts that evolution leads to the increase of information and intelligence, and the evolution of stars should not form exception to this. Also the interpretation of black hole as consisting of dark matter follows from this picture.

Summarizing, it seems that thanks to some crucial experimental inputs the new physics predicted by TGD is becoming testable in laboratory.

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