

# Cosmology and Astrophysics in Many-Sheeted Space-Time

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## Contents

<b>1</b>	<b>Introduction</b>	<b>5</b>
<b>2</b>	<b>How do General Relativity and TGD relate?</b>	<b>8</b>
2.1	The problems . . . . .	8
2.2	The new view about energy as a solution of the problems . . .	9
2.3	Basic predictions at quantitative level . . . . .	12
2.3.1	Membrane like objects and the p-adic evolution of cosmological constant . . . . .	13
2.3.2	Cosmic strings and the value of cosmological constant	15
2.3.3	Do absolute minima of Kähler action satisfy the inertial counterpart of Einstein's equations? . . . . .	17
2.3.4	Boundary conditions in presence of cosmological constant . . . . .	18
2.3.5	$CP_2$ type extremals and Einstein's equations . . . . .	19
2.4	Non-conservation of gravitational four-momentum . . . . .	19
<b>3</b>	<b>TGD inspired cosmology</b>	<b>21</b>
3.1	Robertson-Walker cosmologies . . . . .	23
3.1.1	Why Robertson-Walker cosmologies? . . . . .	24
3.1.2	Imbeddability requirement for RW cosmologies . . . . .	24
3.1.3	Critical and over-critical cosmologies . . . . .	25
3.1.4	More general imbeddings of critical and over-critical cosmologies as vacuum extremals . . . . .	28
3.1.5	String dominated cosmology . . . . .	29
3.1.6	Stationary cosmology . . . . .	30

3.1.7	Non-conservation of gravitational energy in RW cosmologies . . . . .	31
<b>4</b>	<b>Cosmic strings and cosmology</b>	<b>34</b>
4.1	Basic ideas . . . . .	34
4.1.1	The relationship between inertial and gravitational masses . . . . .	34
4.1.2	Topological condensation of cosmic strings . . . . .	35
4.1.3	Cosmic strings and generation of structures . . . . .	37
4.1.4	Correlation between super-novae and cosmic strings . . . . .	37
4.2	Free cosmic strings . . . . .	39
4.3	Pairing of strings as a manner to satisfy Einstein's equations	43
4.4	Reduction of the $m_I/m_{gr}$ ratio as a vacuum polarization effect?	44
4.5	Generation of ordinary matter via Hawking radiation? . . . . .	44
4.5.1	A more detailed picture . . . . .	45
4.5.2	The new view about Second Law . . . . .	47
4.5.3	Creation of matter from vacuum by annihilation of laser waves and their phase conjugates? . . . . .	48
4.6	Cosmic strings and cosmological constant . . . . .	49
4.6.1	Cosmological constant for the internal dynamics of strings . . . . .	49
4.6.2	p-Adic evolution of cosmological constant . . . . .	52
4.6.3	Cosmological constant for the Kähler neutral space-time sheets carrying pairs of strings . . . . .	52

## Abstract

This chapter is devoted to the applications of what might be called classical TGD to astrophysics and cosmology. In a well-defined sense classical TGD defined as the dynamics of space-time surface determining them as kind of generalized Bohr orbits can be regarded as an exact part of quantum theory and assuming quantum classical correspondence has served as an extremely valuable guideline in the attempts to interpret TGD, to form a view about what TGD really predicts, and to guess what the underlying quantum theory could be and how it deviates from standard quantum theory. Also TGD inspired cosmology and astrophysics relies on this general picture.

### 1. *Many-sheeted cosmology*

The many-sheeted space-time concept, the new view about the relationship between inertial and gravitational four-momenta, the basic properties of the paired cosmic strings, the existence of the limiting temperature, 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.

The most important differences are following.

a) Many-sheetedness implies cosmologies inside cosmologies Russian doll like structure with a spectrum of Hubble constants.

b) TGD cosmology is also genuinely quantal: each quantum jump in principle recreates each sub-cosmology in 4-dimensional sense: this makes possible a genuine evolution in cosmological length scales so that the use of anthropic principle to explain why fundamental constants are tuned for life is not necessary.

c) The new view about energy means that inertial energy is negative for space-time sheets with negative time orientation and that the density of inertial energy vanishes in cosmological length scales. Therefore any cosmology is in principle creatable from vacuum and the problem of initial values of cosmology disappears. The density of matter near the initial moment is dominated by cosmic strings approaches to zero so that big bang is transformed to a silent whisper amplified to a relatively big bang.

d) Dark matter hierarchy with dynamical quantized Planck constant implies the presence of dark space-time sheets which differ from non-dark ones in that they define multiple coverings of  $M^4$ . Quantum coherence of dark matter in the length scale of space-time sheet involved implies that even in cosmological length scales Universe is more like a living organism than a thermal soup of particles.

e) Sub-critical and over-critical Robertson-Walker cosmologies are fixed completely from the imbeddability requirement apart from a sin-

gle parameter characterizing the duration of the period after which transition to sub-critical cosmology necessarily occurs. The fluctuations of the microwave background reflect the quantum criticality of the critical period rather than amplification of primordial fluctuations by exponential expansion. This and also the finite size of the space-time sheets predicts deviations from the standard cosmology.

### 2. Cosmic strings

Cosmic strings belong to the basic extremals of the Kähler action. The string tension of the cosmic strings is  $T \simeq .2 \times 10^{-6}/G$  and slightly smaller than the string tension of the GUT strings and this makes them very interesting cosmologically. Concerning the understanding of cosmic strings a decisive breakthrough came through the identification of gravitational four-momentum as the difference of inertial momenta associated with matter and antimatter and the realization that the net inertial energy of the Universe vanishes. This forced to conclude cosmological constant in TGD Universe is non-vanishing. p-Adic length fractality predicts that  $\Lambda$  scales as  $1/L^2(k)$  as a function of the p-adic scale characterizing the space-time sheet. The recent value of the cosmological constant comes out correctly. The gravitational energy density described by the cosmological constant is identifiable as that associated with topologically condensed cosmic strings and of magnetic flux tubes to which they are gradually transformed during cosmological evolution.

p-Adic fractality and simple quantitative observations lead to the hypothesis that pairs of cosmic strings are responsible for the evolution of astrophysical structures in a very wide length scale range. Large voids with size of order  $10^8$  light years can be seen as structures containing knotted and linked cosmic string pairs wound around the boundaries of the void. Galaxies correspond to same structure with smaller size and linked around the supra-galactic strings. This conforms with the finding that galaxies tend to be grouped along linear structures. Simple quantitative estimates show that even stars and planets could be seen as structures formed around cosmic strings of appropriate size. Thus Universe could be seen as fractal cosmic necklace consisting of cosmic strings linked like pearls around longer cosmic strings linked like...

### 3. Dark matter and quantization of gravitational Planck constant

The notion of gravitational Planck constant having gigantic value is perhaps the most radical idea related to the astrophysical applications of TGD. D. Da Rocha and Laurent Nottale have proposed that Schrödinger equation with Planck constant  $\hbar$  replaced with what might be called gravitational Planck constant  $\hbar_{gr} = \frac{GmM}{v_0}$  ( $\hbar = c = 1$ ).  $v_0$  is a velocity parameter having the value  $v_0 = 144.7 \pm .7$  km/s giving

$v_0/c = 4.6 \times 10^{-4}$ . This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of  $v_0$  seem to appear. The support for the hypothesis coming from empirical data is impressive.

Nottale and Da Rocha believe that their Schrödinger equation results from a fractal hydrodynamics. Many-sheeted space-time however suggests astrophysical systems are not only quantum systems at larger space-time sheets but correspond to a gigantic value of gravitational Planck constant. The gravitational (ordinary) Schrödinger equation would provide a solution of the black hole collapse (IR catastrophe) problem encountered at the classical level. The resolution of the problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale.

TGD predicts correctly the value of the parameter  $v_0$  assuming that cosmic strings and their decay remnants are responsible for the dark matter. The harmonics of  $v_0$  can be understood as corresponding to perturbations replacing cosmic strings with their  $n$ -branched coverings so that tension becomes  $n^2$ -fold: much like the replacement of a closed orbit with an orbit closing only after  $n$  turns.  $1/n$ -sub-harmonic would result when a magnetic flux tube split into  $n$  disjoint magnetic flux tubes. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

## 1 Introduction

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I have proposed already earlier the possibility that Planck constant is quantized and the spectrum is given in terms of logarithms of Beraha numbers  $B_n = 4\cos^2(\pi/n)$ : the lowest Beraha number  $B_3$  is completely exceptional in that it predicts infinite value of Planck constant. The inverse of the gravitational Planck constant could correspond a gravitational perturbation of this as  $1/\hbar_{gr} = v_0/GMm$ . The general philosophy would be that when the quantum system would become non-perturbative, a phase transition increasing the value of  $\hbar$  occurs to preserve the perturbative character and at the transition  $n = 4 \rightarrow 3$  only the small perturbative correction to  $1/\hbar(3) = 0$  remains. This would apply to QCD and to atoms with  $Z > 137$  as well.

TGD predicts correctly the value of the parameter  $v_0$  assuming that cosmic strings and their decay remnants are responsible for the dark matter. The harmonics of  $v_0$  can be understood as corresponding to perturbations replacing cosmic strings with their  $n$ -branched coverings so that tension becomes  $n^2$ -fold: much like the replacement of a closed orbit with an orbit closing only after  $n$  turns.  $1/n$ -sub-harmonic would result when a magnetic flux tube split into  $n$  disjoint magnetic flux tubes. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

## 2 How do General Relativity and TGD relate?

The two and half decades with TGD have taught that the most important and most difficult problems are those related to the interpretation of the theory. The most difficult lesson has however been that the world view represented by so called well-established theories can be totally wrong, or perhaps better to say not-even-wrong, even when they work amazingly well apart from easily forgotten anomalies.

From the beginning there was an unpleasant feeling that the proposed relationship between TGD and General Relativity might not be elegant enough to be correct. In the sequel I summarize the most important problems, their resolution in terms of new notion of energy, and then discuss in more detailed level the basic predictions.

### 2.1 The problems

There were several closely related problems.

a) How the absolute minimization of Kähler action (or some other principle responsible for selection of preferred extremals [E2] can be consistent



with Einstein's equations? The energy tensor of Kähler action is certainly not proportional to the Einstein tensor.

b) Equivalence Principle encourages the identification of the inertial energy with gravitational energy. But how the exact conservation of inertial energy can be consistent with the non-conservation of gravitational energy defined by the Einstein tensor? Basically the problem is about relationship between inertial and gravitational energy. Poincare invariance does not yet resolve completely the conceptual problems related to the definition of energy.

c) Robertson-Walker cosmologies are imbeddable into  $H = M_+^4 \times CP_2$  but they are vacua with respect to the inertial energy. This forced to give up the very elegant idea that the energy momentum tensor associated with Kähler action would correspond to the classical energy.

Also General Relativity has its problems.

a) The problem of cosmological constant is the most acute problem of General Relativity and also of string models and of M-theory. Recent experimental findings support the view that cosmological constant might be non-vanishing. In TGD Einstein's equations emerge as structural equations and the finite size of space-time sheets allows a non-vanishing cosmological constant also in TGD. My personal strong belief has been that cosmological constant vanishes and the justification has been that the action with a cosmological constant becomes infinite. Unfortunately, the situation changes if Einstein's equations are not derivable from action but are structural equations. Note also that if space-time sheets have a finite temporal extension the volume term in action becomes finite.

b) 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.

## 2.2 The new view about energy as a solution of the problems

The solution to these problems did not emerge by staying inside the framework of respected physics, and the frame of mind making possible the liberation from the jail of old ideas evolved only gradually. Basically this occurred during last decade when I played with ideas related with quantum consciousness, quantum biology, and over unity energy production claimed by free energy people.

The liberation process was initiated by a simple observation which led to the identification of what I believe to be the basic mechanism of conscious information processing and functioning of living matter [K1, K4, K6]. Since

space-time is 4-surface, the sign of energy depends on the time orientation. The identification of phase conjugate photons as negative energy photons allows readily to understand their mysterious properties and communication and control of geometric past in terms of negative energy signals becomes possible as well as remote metabolism by emitting negative energy particles received by a system acting as energy reservoir.

It took few years until I found myself asking whether phase conjugation might make sense for also fermions, and whether one could resolve the puzzle of matter antimatter asymmetry by assuming that anti-fermions carry negative energies. The idea that it might be possible to generate material objects from vacuum remained for a long time too high a threshold for taking this idea seriously. The pleasant realization was that these ideas are immediately testable by just looking whether pairs of photons and their phase conjugates can annihilate to pairs of electrons and negative energy positrons. Needless to say, the technological implications for energy and information technologies are something which no one has dared to dream of.

This bottle neck idea led rather rapidly to quite a dramatic revision of the vision about the world around us and resolved elegantly the interpretational problems.

a) The most predictive variant of TGD assumes that the net conserved quantum numbers of the Universe vanish. Both quantum and classical worlds are vacua and these vacua are replaced with new ones in each quantum jump. Crossing symmetry guarantees that the new picture is consistent with elementary particle physics. In fact, I used years ago crossing symmetry to derive S-matrix and high energy limit and indeed interpreted the zero energy system as kind of cognitive representation for the real world system.

b) The interpretation necessitates negative energies. In TGD Universe all elementary particles have as their building blocks fermions and anti-fermions. Thus if phase conjugate photons are possible they must result by a phase conjugation performed for fermions. Taking this idea seriously leads to the identification of the phase conjugate fermions as states created from a fermionic vacuum for which the roles of creation and annihilation operators are changed.

One can go even further and consider the possibility that this role change can occur separately for fermions and anti-fermions: in this kind of situation both fermion and anti-fermion oscillator operators would be creation operators or annihilation operators. These novel kinds of vacua can carry only positive/negative fermion number and inertial energy can vanish so that they would be naturally associated with nearly vacuum extremals. For the conventional vacua net fermion number can vanish whereas energy cannot

vanish. The separate conservation of quark and lepton numbers in principle doubles the bits labelling the possible vacua.

c) The Eastern vision about particle reactions as creation of positive and negative energy particles from vacuum encourages also a more refined view about particle massivation. In TGD Universe total energy vanishes. This would mean that massive gauge bosons can be created from vacuum with appreciable probably only as pairs of positive and negative energy bosons. The Compton wave length of intermediate boson would define the p-adic length scale giving the size of the pair and imply also its instability. In the case of fermions, say electron, the situation cannot be quite so simple. p-Adic mass calculations rely on the idea that massless states mix slightly with states having  $CP_2$  mass scale and the dominant massless contribution explains the stability of electron. Intermediate gauge bosons have a genuine coupling to the TGD counterpart of Higgs field which could explain the mass of the bosons whereas for fermions this contribution is small (there is also a second mechanism based on the lacking covariant constancy of intermediate boson charge matrices). Higgs would thus be the basic cause for the inability to create massive gauge boson pairs with too large separation. Analogous picture applies to color confinement: it is not possible to create colored particles from vacuum without negative energy companion outside the confinement length.

d) The energy momentum tensor of the Kähler action corresponds to the net energy density of matter and antimatter. For vacuum extremals these energies cancel each other. Thus the gigantic vacuum degeneracy of Kähler action finally finds a precise physical meaning. In particular, this holds true in cosmological length scales.

e) Equivalence Principle holds true in the sense that gravitational mass is the *absolute* value of inertial mass and the energy density appearing in Einstein's equations corresponds to the *difference* of the energy densities associated with matter and antimatter and is thus positive. Since gravitational energy density is the difference of matter and antimatter energy densities, it is conserved at the classical limit when the annihilation of matter and antimatter is negligible. Einstein's equations are structural equations, kind of equations of state and gravitational constant and cosmological constant can vary.

This would resolve the puzzle created by the finding made already during the first years of TGD. The mystery was that for space-time surfaces which are surfaces in  $M^4_+ \times S^2$ , where  $S^2$  is homologically nontrivial geodesic sphere, Kähler energy density satisfies approximately Einstein's equation but with gravitational coupling  $G_{eg}$ , which is about  $10^7$  times stronger than Newton's

constant. Similar conclusion holds true for cosmic strings.

The correct interpretation is that the density of inertial energy is in good approximation a fraction  $10^{-7}$  about the density of gravitational energy so that there is slight matter antimatter asymmetry. For vacuum extremals  $G_{eg}$  is formally infinite and one could speak of strong gravity. The earlier interpretation was in terms of electro-gravity based on hypothesis that gravitation couples more strongly to classical fields and recent interpretation allows to give up this hypothesis. The principle selecting preferred extremals of Kähler action as generalized Bohr orbits (absolute minimizations or something more general [E2]) is the fundamental classical dynamics serving as a kind of symbolic representation of quantum dynamics, and the dynamics of Einstein tensor is determined by it.

f) p-Adic length scale hypothesis plus the detailed study of membrane like vacuum extremals lead to the hypothesis that cosmological constant depends on p-adic length scale  $\Lambda/R^2 \propto 1/R^2 L^2(k) \propto 2^{-k}$ . Amazingly, the recent value of the cosmological constant suggested by the accelerated expansion of the Universe comes out as a correct prediction!

Cosmological expansion at a particular space-time sheet becomes a TGD counterpart for a sequence of periods of increasingly slow inflation which a reduction of  $\Lambda$  by a factor of 2 at each time when the size of space-time sheet exceeds a p-adic length scale. It must be however emphasized that Kähler action determines the classical dynamics and it is by no means clear that exponential expansion is involved. What certainly occurs is liberation of gravitational energy, which means that the difference of inertial energy densities for matter and antimatter is reduced in a phase transition like manner. Maybe the interpretation in terms of annihilation of matter and antimatter is appropriate. Perhaps particles with masses of order p-adic length scale become non-relativistic and annihilate to lighter particles, most naturally those corresponding to the next p-adic length scale.

One must consider also the possibility that the sign of  $\Lambda$  is negative. This would imply that at each step when  $\Lambda$  is reduced by a factor of two, cosmic expansion suffers kind of a jerk and then starts to slow down. The requirement that the gravitational energy is positive however favors positive value of  $\Lambda$ .

### 2.3 Basic predictions at quantitative level

In the following I consider basic quantitative predictions following from the proposed scenario by studying some of the simplest extremals of Kähler action.

### 2.3.1 Membrane like objects and the p-adic evolution of cosmological constant

The first argument in favor of a non-vanishing cosmological constant comes from the requirement that gravitational energy is larger or equal than the absolute value of the inertial energy. If cosmological constant vanishes, one might argue that the gravitational energy of any 3-surface of finite size vanishes. This would require that also the inertial energy vanishes. The way out of dilemma is to assume that energy density contains also the contribution corresponding to cosmological constant which is proportional to volume. Actually this argument must be taken with a big grain of salt as following more convincing argument demonstrates.

The density of gravitational energy should be non-negative always and this forces to introduce cosmological constant as the following argument shows.

Consider membrane like vacuum extremals of form  $X^4 = M^1 \times X^2 \times S^2$ , where  $S^1$  is circle in  $CP_2$ ,  $M^1$  corresponds to time axis of  $M^4$  and  $X^2$  is arbitrary two-surface. Inertial energy density vanishes for this surface so that matter and antimatter energies cancel each other locally. Einstein tensor is given by

$$G^{\alpha\beta} = R^{\alpha\beta}(X^2) - \frac{1}{2}g^{\alpha\beta}R(X^2) . \quad (1)$$

One can integrate the contribution of the Einstein tensor to the total energy (one can multiply  $G^{\alpha\beta}$  the vector field generating time translation in  $M^4_+$  to get a vector field) to get given by

$$16\pi G \times E_{gr} = -\frac{1}{2}L(S^1) \times \int_{X^2} R(X^2)d^2x = \frac{1}{2}L(S^1) \times 2\pi(g-1) . \quad (2)$$

Note that  $\xi(X^2) = 1-g$  is the Euler characteristic and  $g$  denotes the number of handles of the two surface. The gravitational energy would be negative for spherical topology without a compensating cosmological contribution from the action  $S = \hat{\Lambda} \int \sqrt{|g|}d^4x$ ,  $\hat{\Lambda} \equiv 8\pi G\Lambda$ :

$$E_{vac} = \hat{\Lambda}L(S^1) \times S(X^2) . \quad (3)$$

Here  $S(X^2)$  denotes the area of the two-surface.

Cosmological constant  $\Lambda$  can depend on the p-adic length scale characterizing the size of  $X^2$ . In fact, it seems that this must be the case. First of all, for very small radii the contribution of the Einstein tensor implies negative gravitational energy irrespective of the value of  $\Lambda$ . One can however assume that  $\Lambda$  scales as  $1/L_{p,n}^2$  where  $L_{p,n} = p^{(n-1)/2}L_p$  is the n-ary p-adic length scale characterizing the size of  $X^2$ . For  $n = 1$  one obtains the hierarchy  $L_p = \frac{\sqrt{p}}{\sqrt{2}}L_2$  of p-adic length scale with  $p \simeq 2^k$ ,  $k$  integer, defining the physically favored p-adic length scales. This would mean that the contribution of the cosmological constant term does not grow with surface area in long length scales. For p-adic length scales below  $L_2$  which is of order  $CP_2$  size, the scales  $n = -1, -2, ..$  become possible. For  $n = -1$  the scaling  $\Lambda(k) \propto 2^k/L^2(2)$  takes care that the sum of energies is independent of p-adic length scale.

This hypothesis implies that the value of cosmological constant is in cosmological length scales related by a p-adic scaling to its value at the 2-adic length scale  $L(2) \sim R$ :

$$\frac{\Lambda(k)}{\Lambda(k=2)} = \frac{a^2(2)}{a^2(k)} = 2^{-k+1} . \quad (4)$$

Here  $a(k)$  is the p-adic time scale defined by the p-adic length scale  $L(k)$  identified as Minkowski light cone proper time.  $a(k)$  increases by a factor 2 in each phase transition reducing the value of the cosmological constant. The implication is that cosmological constant decreases as  $1/a^2$  one the average. This provides an elegant solution to the mysterious smallness of cosmological constant assuming just the naive value at the primordial stage.

As known, the naive estimate  $\Lambda_0 \sim 1/G$  implies that the cosmological constant is about  $10^{120}$  times larger than the experimental upper bound for it. This is no doubt the most dramatic discrepancy between theory and experiment known in the history of physics. The detailed discussion of cosmic strings leads to the conclusion that the value of  $\Lambda(2)$  is of order

$$\Lambda(2) \sim \frac{1}{R^2} \sim 10^{-7}\Lambda_0 . \quad (5)$$

This alone does not help much!

The p-adic scaling implies that the recent value of  $\Lambda(a)$  is about

$$\Lambda(a) \sim \sim 10^{-7}\Lambda(2)\frac{a^2(2)}{a^2(k)} = 10^{-7}\Lambda(2)2^{-k+1} . \quad (6)$$

The requirement  $\Lambda(a)/\Lambda(2) \simeq 10^{-120}$  gives  $2^{-k+1} \simeq 10^{-113} \sim (2^{-10})^{113/3}$  gives  $k \sim 378$ . This gives together with  $L(k = 151) = 10$  nm gives  $L(k) = 2^{(k-151)/2} \times L(151) \sim 2^{113} L(151) \sim 10^{26}$  m which corresponds to  $10^{11}$  light years and to a good estimate for the recent age of the universe. Thus this simple argument resolves elegantly the hugest discrepancy in the history of theoretical physics (only in cosmology one can tolerate so cosmic discrepancies!).

### 2.3.2 Cosmic strings and the value of cosmological constant

In TGD framework cosmic strings are objects of form  $X^4 = X^2 \times S_I^2$ , where  $S_I^2$  is the homologically non-trivial geodesic sphere of  $CP_2$ . Non-vacuum extremals of Kähler carrying ultra-strong Kähler magnetic field are in question. For simplicity one can assume that  $X^2$  is a flat piece  $M^2$  of  $M_+^4$  so that the Einstein tensor has expression

$$G^{\alpha\beta} = \mathbf{R}(S_I^2) - \frac{1}{2} \mathbf{g} R(S_I^2) . \quad (7)$$

where  $R(S_I^2)$  denotes the curvature scalar. The energy density  $G^{tt} = -(1/2)R(S_I^2)$  is negative because of spherical topology. Obviously cosmic strings correspond to the p-adic length scale  $L(2)$  naturally so that it should be possible to deduce a lower bound for  $\Lambda(2)$  from the requirement that gravitational energy density is non-negative.

There are actually two constraints involved.

a) The first constraint comes from the sum of the energies of matter and antimatter expressible as the energy of Kähler field. A priori one cannot exclude the possibility that for cosmic strings the quantization in fermionic sector is such that both fermions and anti-fermions are either positive or negative. This requires that cosmic strings created in the big bang or possibly later appear in pairs which opposite vacuum energies. Since very simple objects are in question this might be the case although arbitrary small difference of induced metrics might be amplified into infinitely large difference in zero point energies.

The energy momentum tensor for Kähler field and Einstein tensor can be written as

$$\begin{aligned} \mathbf{T}_K &= \frac{1}{2 \times 16\pi\alpha_K R^4} (\mathbf{g}(M^2) - \mathbf{g}(S^2)) , \\ \mathbf{G} &= -\frac{4}{R^2} \mathbf{g}(M^2) . \end{aligned} \quad (8)$$

Note that the radius of  $S_I^2$  is  $R/4$  for the conventions used.

$\mathbf{T}_K$  can be written as sum of Einstein tensor and metric tensor as

$$\begin{aligned}\mathbf{T}_K &= \frac{1}{16\pi G_{eg}} \mathbf{G} + \hat{\Lambda}_{eg} \mathbf{g} , \\ G_{eg} &= 8R^2 \alpha_K , \\ \hat{\Lambda}_{eg} &= \frac{1}{2R^4 \times 16\pi \alpha_K} .\end{aligned}\tag{9}$$

Note that the ratio  $G_{eg}/G = \frac{8R^2}{G} \alpha_K$  is much larger than one.

The study of simple imbeddings of Maxwell field to  $M^4 \times S_I^2$ , demonstrates that Einstein's equations hold true approximately also more generally in the non-relativistic approximation and the value of  $G_{eg}$  is as above. This raises the possibility that the dynamics of Kähler action could be reflected in phenomena of electro-gravitation and that near vacuum extremals could be seen as a limit at which electro-gravitational coupling strength becomes very large.

There would be thus two "gravitations": one for the sum and one for the difference of energies of matter and antimatter. The consistency with the existing theory requires an approximate separate conservation of these energies meaning that the annihilation of matter and antimatter can be neglected. TGD based models for the asymptotic cosmology and the asymptotic state of star rely on this assumption.

b) Gravitational energy tensor can be written as a sum of Einstein tensor and metric tensor

$$\mathbf{T}_{gr} = \frac{1}{16\pi G} \mathbf{G} + \Lambda(2) \mathbf{g} .\tag{10}$$

c) The basic constraint comes from the requirement that irrespective of the option chosen for the fermionic quantization one has

$$E_{gr} \geq E_K ,\tag{11}$$

where one has

$$\begin{aligned}E_{gr} &= -\frac{1}{16G} + \hat{\Lambda}(2) \frac{\pi R^2}{4} , \\ E_K &= -\frac{1}{16G_{ge}} + \hat{\Lambda}_{ge} \frac{\pi R^2}{4} = \frac{1}{4 \times 16\alpha_K R^2} .\end{aligned}\tag{12}$$



The lower bound means that the two terms in gravitational energy nearly cancel each other since the right hand side is of order  $10^{-7}$  as compared to the left hand side. One has

$$\hat{\Lambda}(2) \geq \frac{1}{16R^4} \left[ \frac{16R^2}{G} + \frac{1}{\alpha_K} \right]. \quad (13)$$

For the minimal value of  $\Lambda(2)$  gravitational and inertial energies are identical. This corresponds to the situation in which negative energy contribution to the inertial energy vanishes. This situation can result in two manners. Either antimatter is absent or fermionic quantization is performed in the standard manner. The latter option fixes the value of  $\hat{\Lambda}(2)$  completely.

The cancellation of the total inertial energy can be achieved if strings have opposite time directions and the zero energy fermionic ground states for the two strings are phase conjugates of each other. Strings with conventional fermionic vacua can emit positive energy fermions during later stages of evolution: this reduces the energy density of the string. If the stringy fermionic vacuum is unconventional, the string can generate fermion anti-fermion pairs during later phases of cosmic evolution such that the negative energy member of the pair remains inside string and reduces its energy density (note that fermion number increases!). These arguments generalize to phase conjugate strings. The reduction of the energy density means a thickening of the string since flux quantization condition must be satisfied. Energy density behaves as  $1/S$  during this process.

More detailed considerations [D4, D5] show that only the non-conventional vacua are consistent with the galactic rotation curves favoring  $T_{gr} \sim 1/R^2$  rather than  $T_{gr} \sim 1/G$  predicted by the mechanism based on the conventional stringy vacua.

### 2.3.3 Do absolute minima of Kähler action satisfy the inertial counterpart of Einstein's equations?

Quantum classical correspondence suggests that the preferred extremals of Kähler action are able to represent "symbolically" various aspects of the dynamics of quantum jumps, also dissipation. In particular, the preferred extremals should asymptotically serve as space-time correlates of non-dissipating self-organization patterns. This requires that Lorentz Kähler force vanishes. This ansatz leads to a construction of very general solution families for the field equations.

The vanishing of Lorentz Kähler force implies that the energy momentum tensor  $T_K^{\alpha\beta}$  associated with Kähler action has a vanishing covariant divergence. This raises the question whether it could be expressible as a linear combination of induced metric and Einstein tensor:

$$T_K^{\alpha\beta} = \frac{1}{16\pi G_{eg}} G^{\alpha\beta} + \hat{\Lambda}_{eg} g^{\alpha\beta} . \quad (14)$$

Since inertial energy momentum is in question, the counterparts of Newton's constant and cosmological constant must differ from their gravitational counterparts as they indeed do according to the previous considerations.

The strongly non-deterministic dynamics of vacuum extremals (with respect to inertial energy only) brings strongly in mind 4-dimensional topological quantum field theories and one can ask whether the time evolution could in some sense define a topological quantum field theory providing information about the topology of the vacuum extremal. The vacuum extremal property could pose constraints on the four-topology and also define non-trivial cobordism theory for 3-topologies.

#### 2.3.4 Boundary conditions in presence of cosmological constant

When space-time sheet has boundaries the conservation of gravitational energy gives additional conditions. One must assign energy momentum tensor  $T_\delta^{\alpha\beta}$  to the boundary. The boundary counterpart of Einstein's equations can be written as

$$D_\beta T_\delta^{\alpha\beta} = X^\alpha , \quad (15)$$

where  $X^\alpha$  corresponds to the variation of the boundary term resulting from the variation of the Einstein action  $(\kappa R + \hat{\Lambda})\sqrt{g}$  in the interior. Only the first and second derivatives of the interior action contribute to the boundary term so that cosmological constant term does not contribute to the boundary term. One has

$$X^\alpha = \kappa \left\{ - \left[ \frac{\partial(R\sqrt{g})}{\partial g_{\alpha\beta|\gamma n}} \right]_{|\gamma} + \frac{\partial(R\sqrt{g})}{\partial g_{\alpha\beta|n}} \right\} . \quad (16)$$

The requirement that gravitational energy does not leak out from the space-time sheet gives the boundary conditions

$$\kappa G^{n\alpha} + \hat{\Lambda} g^{n\alpha} = X^\alpha . \quad (17)$$

These conditions refer only to the metric and it should be relatively easy to satisfy these conditions in the case of vacuum extremals of Kähler action. In case of flat 4-surfaces it is obviously not possible to satisfy the boundary conditions.

### 2.3.5 $CP_2$ type extremals and Einstein's equations

One might argue that Einstein's equations provide a phenomenological description of many-particle system and it is not possible to apply them to  $CP_2$  extremals. One can still look what one obtains in this manner. Since vacuum extremals are in question inertial energy density vanishes and one has  $T_+ = -T_-$ . If  $CP_2$  extremals carry elementary particle quantum numbers, such as fermion number, this is possible only if bosonic energy cancels fermionic energy.

Since  $CP_2$  is a constant curvature space, Einstein tensor is proportional to the metric tensor  $G^{\alpha\beta} = -\frac{8}{R^2}g^{\alpha\beta}$ . The contribution to the gravitational energy is negative. If one assumes that cosmological constant is same as for cosmic strings and equals to  $\hat{\Lambda}(2)$ , one obtains an additional positive and dominating contribution to the gravitational energy.

## 2.4 Non-conservation of gravitational four-momentum

TGD predicts non-conservation of gravitational four-momentum. The interpretation as a non-conservation of the difference of four-momenta of positive and negative energy matter replaces the previous interpretation as a flow of inertial four-momentum between different space-time sheets and this alters the previous picture (my apologies for my readers: do not lose your patience!).

The standard belief is that a compact 3-manifold must have a vanishing gravitational mass. In TGD framework this would mean that the gravitational mass of the vapor phase particles vanishes. As already seen, this is not the case in TGD without further assumptions about the dynamics of topological evaporation. Although the evaporated particle does not interact via classical long range gravitational fields, it can interact via the emission and absorption of gravitons. This should indeed be the case if the particle has a vanishing gravitational mass. But since gravitons form join bonds with the external world, the system would not actually be like an isolated

universe. If particle is topologically evaporated in strict four-dimensional sense, it must satisfy empty space Einstein equations with a cosmological term, and be a vacuum extremal so that it does not carry either matter or antimatter and is rather uninteresting physically.

If the space-time sheets of 3-surface has no wormhole contacts (topological sum contacts) with larger space-time sheets, it is like an isolated universe, and its inertial mass should vanish and be small if the number of these contacts is small. By the same argument also Lorentz-, color-, fermionic, etc. quantum numbers of the evaporated space-time sheet should vanish. This does not mean that the space-time sheet could not be in motion and possess cm momentum and angular momentum. The point is that these quantum numbers are compensated by the correspond quantum numbers in internal degrees of freedom. Situation changes in the case of non-conserved quantum numbers and the quantum numbers associated with the representations of super-canonical symmetries (discussed in the chapters of the first part of the book) could be non-vanishing.

The inertial mass possibly possessed by a topologically evaporated particle is left at the boundaries of holes resulting in the evaporation. Topologically evaporated particle can indeed develop negative inertial energy density at its boundaries guaranteing the vanishing of its inertial mass since space-time sheets with negative time orientation possess negative energy.

One can evaluate the divergence of the gravitational energy momentum tensor satisfying Einstein equations with a cosmological term by calculating the divergence of the four momentum current  $T^{A\alpha}$  ( $A$  labels different momentum components)

$$D_\alpha T^{A\alpha} = \left[ \frac{1}{16\pi G} G^{\alpha\beta} + \hat{\Lambda}(2)g^{\alpha\beta} \right] H_{\alpha\beta}^k j_k^A . \quad (18)$$

Here  $j^{Ak}$  denotes the Killing vector of translation. This equation will be applied later in the context of Robertson-Walker cosmologies.

A situation of a special physical interest corresponds to the separate conservation of inertial and gravitational masses. In this case the following equations of motion derivable from Einstein action  $S = \int (kR + \hat{\Lambda}(2))\sqrt{g}d^4x$ ,  $k = 1/16\pi G$ , hold true

$$\left[ kG^{\alpha\beta} + \hat{\Lambda}(2)g^{\alpha\beta} \right] H_{\alpha\beta}^k = 0 . \quad (19)$$

At cosmological length scales the cosmological term is negligible, and one can replace the equation with

$$G^{\alpha\beta}H_{\alpha\beta}^k = 0 . \quad (20)$$

This action was my first attempt to try to construct "sub-manifold gravity". This equation is expected to provide a reasonable when the energies associated with matter and antimatter are separately conserved.

For Schwartzchild metric the divergence indeed vanishes identically if  $\hat{\Lambda}(2)$  is vanishing (or sufficiently small as in the recent Universe). One can say that stationary situations in which gravitational mass is conserved are those in which gravitational mass appears as lumps. Thus asymptotic self-organization patterns necessarily correspond to gravitational lumping of the matter. In the case of general Reissner-Nordström metric energy flow turns out to be non-vanishing although the metric itself is stationary in the sense of GRT. It will be later found that the Robertson-Walker cosmology satisfying stationarity conditions is essentially unique and provides a natural candidate for the asymptotic cosmology.

The earlier interpretation for the non-conservation of gravitational four-momentum was in terms of a loss of inertial four-momentum due to topological evaporation and flow between different space-time sheets. This interpretation must be given up. If the flow occurs along join along boundaries bonds then the fluxes of energy momentum currents through the cross sections of join along boundaries bonds give the net flow. Not only the flow of energy-momentum but also the flow of fermion numbers, charges, etc., can occur between various space-time sheets. In particular, the flow of entropy is possible. An interesting possibility is that the vapor phase could serve as a "cosmic paper basket" allowing to circumvent the consequences of the second law of thermodynamics: the creation of order through gravitational interactions would become possible in topological condensate through the transfer of entropy to the vapor phase.

### 3 TGD inspired cosmology

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 (Kähler coupling strength is analogous to critical temperature) 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.

Any one-dimensional sub-manifold 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 quantum 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. 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.

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 [D6]. Fractal cosmology predicts cosmos to have essentially same optical properties as inflationary scenario. 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.

Absolutely essential element of the considerations (and longstanding puzzle of TGD inspired cosmology) is the conservation of energy implied by Poincare invariance which seems to be in conflict with the non-conservation of gravitational energy. It took long time to discover the natural resolution of the paradox. In TGD Universe matter and antimatter have opposite energies and gravitational four-momentum is identified as difference of the four momenta of matter and antimatter (or vice versa, so that gravitational energy is positive). The assumption that the net inertial energy density vanishes in cosmological length scales is the proper interpretation for the fact that Robertson-Walker cosmologies correspond to vacuum extremals of Kähler action.

Tightly bound, possibly coiled pairs of cosmic strings are the basic building block of TGD inspired cosmology and all structures including large voids, galaxies, stars, and even planets can be seen as pearls in a cosmic fractal necklace consisting of cosmic strings containing smaller cosmic strings linked around them containing... During cosmological evolution the cosmic strings are transformed to magnetic flux tubes and these structures are also key players in TGD inspired quantum biology.

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 gradual red-shifting of the microwave background radiation at particle level. 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.

### 3.1 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 not possible at all.

### 3.1.1 Why Robertson-Walker cosmologies?

Robertson Walker cosmology, which is a vacuum extremal of the Kähler action, is a reasonable idealization only in the length scales, where the density of the Kähler charge vanishes. Since (visible) matter and antimatter carry Kähler charges of opposite sign this means that Kähler charge density vanishes in length scales, where matter-antimatter asymmetry disappears on the average. This length scale is certainly very large in present day cosmology: in the proposed model for cosmology its present value is of the order of  $10^8$  light years: the size of the observed regions containing visible matter predominantly on their boundaries [21]. That only matter is observed can be understood from the fact that fermions reside dominantly at future oriented space-time sheets and anti-fermions on past-oriented space-time sheets.

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.

### 3.1.2 Imbeddability requirement for RW cosmologies

Standard Robertson-Walker cosmology is characterized by the line element [20]

$$ds^2 = f(a)da^2 - a^2\left(\frac{dr^2}{1 - kr^2} + r^2d\Omega^2\right) , \quad (21)$$

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

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

$$ds^2 = da^2 - a^2\left(\frac{dr^2}{1 + r^2} + r^2d\Omega^2\right) . \quad (22)$$

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

$$\begin{aligned} a &= \sqrt{(m^0)^2 - r_M^2} , \\ r_M &= ar . \end{aligned} \quad (23)$$



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

$$s^k = f^k(a) . \quad (24)$$

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

$$\rho = \frac{3}{8\pi G a^2} \left( \frac{1}{g_{aa}} + k \right) . \quad (25)$$

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

$$\begin{aligned} \phi &= f(a) , \\ g_{aa} &= 1 - \frac{R^2}{4} (\partial_a f)^2 . \end{aligned} \quad (26)$$

where  $\phi$  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.

### 3.1.3 Critical and over-critical cosmologies

TGD allows the imbeddings of a one-parameter family of critical over-critical cosmologies. Critical cosmologies are however not inflationary in the sense that they would involve the presence of scalar fields. Exponential expansion is replaced with a logarithmic one so that the cosmologies are in this sense exact opposites of each other. Critical cosmology has been used hitherto as a possible model for the very early cosmology. What is remarkable that this cosmology becomes vacuum at the moment of 'Big Bang' since mass density behaves as  $1/a^2$  as function of the light cone proper time. Instead of 'Big Bang' one could talk about 'Small Whisper' amplified to bang gradually. This is consistent with the idea that space-time sheet begins as a vacuum space-time sheet for some moment of cosmic time. As an imbedded 4-surface this cosmology would correspond to a deformed future light cone having its

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

Consider now in more detail the imbeddings of the critical and over-critical 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 Lagrange manifold of  $CP_2$  would do instead of  $S^2$ ). In the standard coordinates  $(\Theta, \Phi)$  for  $S^2$  and Robertson-Walker coordinates  $(a, r, \theta, \phi)$  for future light cone (, which can be regarded as empty hyperbolic cosmology), the imbedding is given as

$$\begin{aligned} \sin(\Theta) &= \frac{a}{a_1} , \\ (\partial_r \Phi)^2 &= \frac{1}{K_0} \left[ \frac{1}{1 - kr^2} - \frac{1}{1 + r^2} \right] , \\ K_0 &= \frac{R^2}{4a_1^2} , \quad k = 0, 1 , \end{aligned} \tag{27}$$

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

The differential equation for  $\Phi$  can be written as

$$\partial_r \Phi = \pm \sqrt{\frac{1}{K_0} \left[ \frac{1}{1 - kr^2} - \frac{1}{1 + r^2} \right]} . \tag{28}$$

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  $r \rightarrow 1$   $\Phi$  approaches constant  $\Phi_0$  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

$$ds^2 = da^2 - a^2 \left( \frac{dr^2}{1 - kr^2} + r^2 d\Omega^2 \right) . \quad (29)$$

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  $k = 1$ .

$$\begin{aligned} g_{aa} &= 1 - K , \\ K &\equiv K_0 \frac{1}{(1 - u^2)} , \\ u &\equiv \frac{a}{a_1} . \end{aligned} \quad (30)$$

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

$$\begin{aligned} \rho &= \frac{3}{8\pi G a^2} \left( \frac{1}{g_{aa}} + k \right) , \quad k = 0, 1 , \\ \frac{1}{g_{aa}} &= \frac{1}{1 - K} , \\ p &= -\left( \rho + \frac{a \partial_a \rho}{3} \right) = -\frac{\rho}{3} + \frac{2}{3} K_0 u^2 \frac{1}{(1 - K)(1 - u^2)^2} \rho_{cr} , \\ u &\equiv \frac{a}{a_1} . \end{aligned} \quad (31)$$

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  $a=\text{constant}$  hyperboloid.

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

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

$$\begin{aligned} r &= \sqrt{\frac{X}{1-X}} , \\ X &= D|k+u| , \\ u &\equiv \cos(\Theta) , \quad D = \frac{r_0^2}{1+r_0^2} \times \frac{1}{C} , \quad C = |k + \cos(\Theta_0)| . \end{aligned} \quad (32)$$

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

$$ds_{eff}^2 = \frac{R^2}{4} [s_{\Theta\Theta}^{eff} d\Theta^2 + s_{\Phi\Phi}^{eff} d\Phi^2] ,$$

$$\begin{aligned}
s_{\Theta\Theta}^{eff} &= X \times \left[ \frac{(1-u^2)}{(k+u)^2} \times \frac{1}{1-X} + 1 - X \right] , \\
s_{\Phi\Phi}^{eff} &= X \times \left[ (1-X)(k+u)^2 + 1 - u^2 \right] .
\end{aligned} \tag{33}$$

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

$$\sin(\Theta) = ka \rightarrow \sqrt{s_{\Phi\Phi}^{eff}} = ka . \tag{34}$$

For  $\Phi$  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

$$g_{aa} = 1 - \frac{R^2 k^2}{4} \frac{s_{\Theta\Theta}^{eff}}{d\sqrt{s_{\Phi\Phi}^{eff}}/d\Theta} \tag{35}$$

In this case the  $1/(1-k^2 a^2)$  singularity of the density of gravitational mass at  $\Theta = \pi/2$  is shifted to the maximum of  $s_{\Phi\Phi}^{eff}$  as function of  $\Theta$  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.

### 3.1.5 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:

$$g_{aa} = K < 1 . \quad (36)$$

The Hubble constant for this cosmology is given by

$$H = \frac{1}{\sqrt{K}a} , \quad (37)$$

and the so called acceleration parameter [20]  $k_0$  proportional to the second derivative  $\ddot{a}$  therefore vanishes. Mass density and pressure are given by the expression

$$\rho = \frac{3}{8\pi G K a^2}(1 - K) = -3p . \quad (38)$$

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.

### 3.1.6 Stationary cosmology

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

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

$$\partial_a(G^{aa}\partial_a\phi\sqrt{g}) = 0 , \quad (39)$$

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

$$\begin{aligned} g_{aa} &= \frac{(1 - 2x)}{(1 - x)} , \\ x &= \left(\frac{C}{a}\right)^{2/3} . \end{aligned} \quad (40)$$

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

$$\begin{aligned}\rho &= \frac{3}{8\pi G a^2} \frac{x}{(1-2x)} , \\ p &= -\left(\rho + \frac{a\partial_a\rho}{3}\right) = -\frac{\rho}{9} \left[3 - \frac{2}{(1-2x)}\right] .\end{aligned}\quad (41)$$

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 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.

### 3.1.7 Non-conservation of gravitational energy in RW cosmologies

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

$$E = \int \rho g^{aa} \partial_a m^0 \sqrt{g} dV . \quad (42)$$

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

$$X \equiv \frac{(dE/da)_{vap}}{E} = \frac{(dE/da + \int |g^{rr}| p \partial_r m^0 \sqrt{g} d\Omega)}{E} , \quad (43)$$

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 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.

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

$$X = \frac{\partial_a(\rho a^3/\sqrt{g_{aa}})}{(\rho a^3/\sqrt{g_{aa}})} + \frac{3pg_{aa}}{\rho a} . \quad (44)$$

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

$$\begin{aligned} X &= X_1 + X_2 , \\ X_1 &= \frac{\partial_a(\rho a^3/\sqrt{g_{aa}})}{(\rho a^3/\sqrt{g_{aa}})} , \\ X_2 &= \frac{pg_{aa}}{\rho a} \times \frac{3 + 2r^2}{(1 + r^2)^{3/2}} . \end{aligned} \quad (45)$$

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

$$\begin{aligned} X &= X_1 + X_2 , \\ X_1 &= \frac{1}{a} \left[ 1 + 3K_0 u^2 \frac{1}{1-K} \right] , \\ X_2 &= -\frac{1}{3a} \left[ 1 - K - \frac{2K_0 u^2}{(1-u^2)^2} \right] \times \frac{3+2r^2}{(1+r^2)^{3/2}} , \\ K &= \frac{K_0}{1-u^2} , \quad u = \frac{a}{a_0} , \quad K_0 = \frac{R^2}{4a_0^2} . \end{aligned} \quad (46)$$



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

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

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

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

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

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

$$\rho < \frac{k}{a^{2+2/3}} \tag{47}$$

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.

## 4 Cosmic strings and cosmology

Cosmic strings belong to the basic extremals of the Kähler action. The string tension of the cosmic strings is  $T \simeq .2 \times 10^{-6}/G$  and slightly smaller than the string tension of the GUT strings and this makes them very interesting cosmologically. Indeed, string like objects play fundamental role in TGD inspired cosmology and also provide TGD based models for the galaxy formation, galactic dark matter, and for the generation of the large voids. Therefore the study of the properties of cosmic strings deserves a separate chapter.

There are two kinds of strings. Free cosmic strings are not minima of the Kähler action (the action has wrong sign) and as such are not physically interesting except possibly at the very early stages of cosmology. The absolute minimization of the Kähler action requires some mechanism compensating the positive action of the free cosmic strings and topologically condensation provides this mechanism. It however became possible to understand what really occurs in topological condensation only after a more precise view about the relationship between inertial and gravitational masses had emerged.

### 4.1 Basic ideas

#### 4.1.1 The relationship between inertial and gravitational masses

Concerning the understanding of the topological condensation of cosmic strings the decisive breakthrough came through the understanding of the relationship between inertial and gravitational masses.

a) TGD predicts that inertial four-momentum is conserved whereas an empirical fact is that gravitational four-momentum is not conserved in cosmological length scales. The solution of the paradox came through the realization that the inertial energies of matter and antimatter have opposite signs if one requires that the vacuum energy associated with second quantized free induced spinor fields vanishes. The most elegant and most predictive theory results if all quantum states of the Universe have vanishing net energy. Gravitational four-momentum can in turn be defined as a difference of inertial momenta associated with matter and antimatter.

b) The study of the simplest extremals of Kähler action demonstrates that cosmological constant in TGD Universe is non-vanishing. What is new that p-adic length fractality predicts that  $\Lambda$  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  $\Lambda$ . 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.

#### 4.1.2 Topological condensation of cosmic strings

Free cosmic strings as such are certainly not absolute minima of Kähler action and they are expected to decay rapidly to ordinary particles. Topological condensation of the cosmic strings with associated generation of the radial Kähler electric field provides a mechanism for the generation of negative action. The requirement that the Kähler electric field leads to the cancellation of the action of the cosmic string implies that cosmic string carries enormous Kähler charge (roughly one unit of Kähler charge per  $CP_2$  radius).

The basic question whether the exterior region of the topologically condensed cosmic string can be modelled using only General Relativity.

a) In Kähler neutral case, an extremely simple imbedding of the straight string exterior metric exists. This model cannot however guarantee the cancellation of the positive Kähler magnetic action. The idea is obvious. If the string generates a sufficiently strong Kähler charge, the negative Kähler electric action cancels the positive Kähler magnetic action of the string.

b) The string creates a gravitational potential consisting of terms assignable to the gravitational mass of string itself and with the Kähler electric field created by it. The problem is that the gravitational constant is predicted to be roughly  $10^7$  times too large. The new view about energy resolves this problem: Kähler energy represents the density of inertial energy and is much smaller than gravitational energy. The cancellation of Kähler action implies that the gravitational mass of string is by a factor about  $10^7$  larger than the inertial mass of the string. Equality is expected in the case that string carries no matter or antimatter besides field energy.

A possible resolution of the problem comes from the observation that cosmic strings must be created from vacuum as pairs of strings with opposite time orientation and inertial energies. For tightly bound, perhaps even coiled, pairs of cosmic strings radial Kähler fields have opposite directions and tend to cancel each other. There is however a slight matter antimatter asymmetry so that the induced Kähler field is not a pure dipole field and can cancel the Kähler magnetic action.

The pairing must be rather precise so that strings form a coiled structure geometrically analogous to a DNA double helix. This structure could contract to a point at the limit  $a \rightarrow 0$  for  $M_+^4$  option. One could say that

two cosmic strings, whose inertial energies are of opposite sign and of equal magnitude are created from vacuum at or shortly after the moment of big bang. For  $M^4$  option the evolution before the moment of big bang could be preceded by a gravitational collapse and one would have a mirror pair of evolutions. Even a sequence of them making up a temporal mirror hall is possible if the reduction of cosmological constant during cosmic evolution initiates gravitational collapse of the space-time sheet containing the strings at some moment. p-Adic fractality and the fact that the evolution of stars ends with a collapse support this view.

c) The two cosmic strings, which are phase conjugates of each other in the sense that fermionic vacua are related by Hermitian conjugation, must reduce the ratio of their inertial and gravitational masses. The simplest options correspond to the growth of gravitational mass and reduction of inertial mass. Depending on the character of the stringy fermionic vacua, it is possible to imagine two different models for how this could occur.

i) If the phase conjugate strings correspond to conventional fermionic vacua and are condensed at space-time sheets  $X_i^4$ ,  $i = I, II$ , assumed to correspond to non-conventional vacua phase conjugates to each other, the vacuum polarization of  $X_i^4$  could generate gravitational mass of order  $10^7 m_I$  but leave inertial mass unaltered. The gravitational string tension of strings as seen from large distance would be given by  $T_{gr} \sim 1/G$  and inertial string tension would remain essentially  $T_I \sim 1/R^2$ , and the two fundamental scales of TGD would correspond to gravitational and inertial masses. The gravitational string tension of cosmic strings explaining the observed galactic rotation curves corresponds to  $T_I$  rather than  $T_{gr} \sim 1/G$ . Hence this option is not favored.

ii) If strings correspond to non-conventional fermionic vacua they could reduce the magnitudes of their inertial masses by the counterpart of Hawking radiation. In this case gravitational mass could remain as such. This option is favored by the galactic rotation curves.

d) The phase conjugacy of two cosmic strings has deep implications for the cosmic and ultimately also for biological evolution (magnetic flux tubes play a fundamental role in TGD inspired biology and cosmic strings are limiting cases of them). The point is that the arrows of geometric time are opposite for the strings and also for positive energy matter and negative energy antimatter. This implies a competition between two dissipative time developments proceeding in different directions of geometric time and looking self-organization and even self-assembly from the point of view of a conscious observer living in an opposite direction of geometric time. This resolves paradoxes created by gravitational self-organization contra second

law of thermodynamics.

### 4.1.3 Cosmic strings and generation of structures

p-Adic fractality and simple quantitative observations lead to the hypothesis that pairs of cosmic strings are responsible for the evolution of astrophysical structures in a very wide length scale range. Large voids with size of order  $10^8$  light years can be seen as structures containing knotted and linked cosmic string pairs wound around the boundaries of the void. Galaxies correspond to same structure with smaller size and linked around the supragalactic strings. This conforms with the finding that galaxies tend to be grouped along linear structures. Simple quantitative estimates show that even stars and planets could be seen as structures formed around cosmic strings of appropriate size. Thus Universe could be seen as fractal cosmic necklace consisting of cosmic strings linked like pearls around longer cosmic strings linked like...

The observed quantization of the cosmic recession velocity [22] supports the proposed view. The space-time sheet containing closed cosmic string pairs is closed solid torus like structure. If photons from a distant astrophysical object are not able to escape this space-time sheet they can be detected after having traversed several times around the closed loop and the red shift is proportional to the number of traversals. In case of larger void the order of magnitude for the quantization is predicted correctly.

### 4.1.4 Correlation between super-novae and cosmic strings

During year 2003 two important findings related to cosmic strings were made.

a) A correlation between supernovae and gamma ray bursts was observed.

b) Evidence that some unknown particles of mass  $m \simeq 2m_e$  and decaying to gamma rays and/or electron positron pairs annihilating immediately serve as signatures of dark matter. These findings challenge the identification of cosmic strings and/or their decay products as dark matter, and also the idea that gamma ray bursts correspond to cosmic fire crackers formed by the decaying ends of cosmic strings. This forces the updating of the more than decade old rough vision about topologically condensed cosmic strings and about gamma ray bursts described in this chapter (old version is left essentially untouched in order to demonstrate how important the experimental input is for the evolution of ideas).

According to the updated model, cosmic strings transform in topological condensation to magnetic flux tubes about which they represent a limiting case. Primordial magnetic flux tubes forming ferro-magnet like structures become seeds for gravitational condensation leading to the formation of stars and galaxies. The TGD based model for the asymptotic state of a rotating star as dynamo [D3] leads to the identification of the predicted magnetic flux tube at the rotation axis of the star as  $Z^0$  magnetic flux tube of primordial origin. Besides  $Z^0$  magnetic flux tube structure also magnetic flux tube structure exists at different space-time sheet but is in general not parallel to the  $Z^0$  magnetic structure. This structure cannot have primordial origin (the magnetic field of star can even flip its polarity).

The flow of matter along  $Z^0$  magnetic (rotation) axis generates synchrotron radiation, which escapes as a precisely targeted beam along magnetic axis and leaves the star. The identification is as the rotating light beam associated with ordinary neutron stars. During the core collapse leading to the supernova this beam becomes gamma ray burst. The mechanism is very much analogous to the squeezing of the tooth paste from the tube.

TGD based models of nuclei [F8] and condensed matter [F9] suggests that the nuclei of dense condensed matter develop anomalous color and weak charges coupling to dark weak bosons having Compton length  $L_w$  of order atomic size. Also lighter copies of weak bosons can be important in living matter. This weak charge is vacuum screened above  $L_w$  and by dark particles below it. Dark neutrinos, which according to TGD based explanation of tritium beta decay anomaly [F8] should have the same mass scale as ordinary neutrinos, are good candidates for screening dark particles. The  $Z^0$  charge unbalance caused by the ejection of screening dark neutrinos hinders the gravitational collapse. The strong radial compression amplifies the tooth paste effect in this kind of situation so that there are hopes to understand the observed incredibly high polarization of  $80 \pm 20$  per cent [24].

TGD suggests the identification of particles of mass  $m \simeq 2m_e$  accompanying dark matter as lepto-pions [F7] formed by color excited leptons, and topologically condensed at magnetic flux tubes having thickness of about lepto-pion Compton length. Lepto-pions would serve as signatures of dark matter whereas dark matter itself would correspond to the magnetic energy of topologically condensed cosmic strings transformed to magnetic flux tubes.

## 4.2 Free cosmic strings

The free cosmic strings correspond to four-surfaces of type  $X^2 \times S^2$ , where  $S^2$  is the homologically nontrivial geodesic sphere of  $CP_2$  [Appendix of the book] and  $X^2$  is minimal surface in  $M_+^4$ . In this section, a co-moving cosmic string solution inside the light cone  $M_+^4(m)$  associated with a given  $m$  point of  $M_+^4$  will be constructed.

Recall that the line element of the light cone in co-moving coordinates inside the light cone is given by

$$ds^2 = da^2 - a^2 \left( \frac{dr^2}{1+r^2} + r^2 d\Omega^2 \right) . \quad (48)$$

Outside the light cone the line element is given

$$ds^2 = -da^2 - a^2 \left( -\frac{dr^2}{1-r^2} + r^2 d\Omega^2 \right) , \quad (49)$$

and is obtained from the line element inside the light cone by replacements  $a \rightarrow ia$  and  $r \rightarrow -ir$ .

Using coordinates ( $a = \sqrt{(m^0)^2 - r_M^2}$ ,  $ar = r_M$ ) for  $X^2$  the orbit of the cosmic string is given by

$$\begin{aligned} \theta &= \frac{\pi}{2} , \\ \phi &= f(r) . \end{aligned} \quad (50)$$

Inside the light cone the line element of the induced metric of  $X^2$  is given by

$$ds^2 = da^2 - a^2 \left( \frac{1}{1+r^2} + r^2 f_{,r}^2 \right) dr^2 . \quad (51)$$

The equations stating the minimal surface property of  $X^2$  can be expressed as a differential conservation law for energy or equivalently for the component of the angular momentum in the direction orthogonal to the plane of the string. The conservation of the energy current  $T^\alpha$  gives

$$\begin{aligned} T_{,\alpha}^\alpha &= 0 , \\ T^\alpha &= T g^{\alpha\beta} m_{,\beta}^0 \sqrt{g} , \\ T &= \frac{1}{8\alpha_K R^2} \simeq .22 \times 10^{-6} \frac{1}{G} . \end{aligned} \quad (52)$$

The string is slightly smaller than that associated with the GUT strings.

The non-vanishing components of energy current are given by

$$\begin{aligned} T^a &= TUa , \\ T^r &= -T \frac{r}{U} , \\ U &= \sqrt{1 + r^2(1 + r^2)f_{,r}^2} . \end{aligned} \tag{53}$$

The equations of motion give

$$U = \frac{r}{\sqrt{r^2 - r_0^2}} , \tag{54}$$

or equivalently

$$\phi_{,r} = \frac{r_0}{r\sqrt{(r^2 - r_0^2)(1 + r^2)}} , \tag{55}$$

where  $r_0$  is an integration constant to be determined later. Outside the light cone the solution has the form

$$\phi_{,r} = \frac{r_0}{\sqrt{r^2 + r_0^2}r\sqrt{1 - r^2}} . \tag{56}$$

In the region inside the light cone, where the conditions

$$r_0 \ll r \ll 1 \tag{57}$$

hold, the solution has the form

$$\begin{aligned} \phi(r) &\simeq \phi_0 + \frac{v}{r} , \\ v &= \frac{r_0}{\sqrt{1 + r_0^2}} , \end{aligned} \tag{58}$$

corresponding to the linearized equations of motion



$$f_{,rr} + \frac{2f_{,r}}{r} = 0 , \quad (59)$$

obtained most nicely from the angular momentum conservation condition.

In co-moving coordinates (in general the co-moving coordinates of sub-light-cone  $M_+^4$ !) the string is stationary. In Minkowski coordinates string rotates with an angular velocity inversely proportional to the distance from the origin

$$\omega \simeq \frac{v}{r_M} \quad (60)$$

so that the orbital velocity of the string becomes essentially constant in this region. For very large values of  $r$  the orbital velocity of the string vanishes as  $1/r$ . Outside the light cone the variable  $r$  is in the role of time and for a given value of the time variable  $r$  strings are straight and one can regard the string as a rigidly rotating straight string in this region.

Inside the light cone, the solution becomes ill defined for the values of  $r$  smaller than the critical value  $r_0$ . Although the derivative  $\phi_{,r}$  becomes infinite at this limit, the limiting value of  $\phi$  is finite so that strings winds through a finite angle. The normal component  $T^r$  of the energy momentum current vanishes at  $r = r_0$  identically, which means that no energy flows out at the end of the string. The coordinate variable  $r$  becomes however bad at  $r = r_0$  (string resembles a circle at  $r_0$ ) and this conclusion must be checked using  $\phi$  as coordinate instead of  $r$ . The result is that the normal component of the energy current indeed vanishes.

Field equations are not however satisfied at the end of the string since the normal component of the angular momentum current (in  $z$ - direction) is non-vanishing at the boundary and given by

$$J^r = Tr^2a . \quad (61)$$

This means that the string loses angular momentum through its ends although the angular momentum density of the string is vanishing. The angular momentum lost at moment  $a$  is given by

$$J = \frac{Tr^2a^2}{2} = \frac{Tr_M^2}{2} . \quad (62)$$

This angular momentum is of the same order of magnitude as the angular momentum of a typical galaxy [23].

In  $M^4$  coordinates singularity corresponds to a disk in the plane of string growing with a constant velocity, when the coordinate  $m^0$  is positive

$$\begin{aligned} r_M &= vm^0 , \\ v &= \frac{r_0}{\sqrt{1+r_0^2}} . \end{aligned} \quad (63)$$

From the expression of the energy density of the string

$$\begin{aligned} T^a &= \frac{ar}{\sqrt{r^2-r_0^2}} , \\ T &= \frac{1}{8\alpha_K R^2} , \end{aligned} \quad (64)$$

it is clear that energy density diverges at the singularity. As also noticed, the string tension is by a factor of order  $10^{-6}$  smaller than the critical string tension  $T_{cr} = 1/4G$  implying angle deficit of  $2\pi$  in GRT so that there is no conflict with General Relativity (unlike in the earlier scenario, in which the  $CP_2$  radius was of order Planck length). The energy of the string portion ranging from  $r_0$  to  $r_1$  is given by

$$E = T\sqrt{(r_1^2-r_0^2)}a = T\sqrt{\delta r_M^2} . \quad (65)$$

It should be noticed that  $M^4$  time development of the string can be regarded as a scaling: each point of the string moves to radial direction with a constant velocity  $v$ .

One can calculate the total change of the angle  $\phi$  from the integral

$$\Delta\phi = \sqrt{\frac{r_0^2}{1+r_0^2}} \int_{r_0}^{\infty} dr \frac{1}{r\sqrt{(r^2-r_0^2)(1+r^2)}} . \quad (66)$$

The upper bound of this quantity is obtained at the limit  $r_0 \rightarrow 0$  and equals to  $\Delta\phi = \pi/2$ .

Cosmic strings lead to a model for the formation of large voids containing galaxies at their boundaries. This model leads to quite a fascinating picture providing new interpretation for the second law of thermodynamics and suggesting how gravitational self assembly circumvents its implications.

### 4.3 Pairing of strings as a manner to satisfy Einstein's equations

The standard view about topologically condensation of cosmic strings would be very simple. The metric of the space-time sheet at which string condenses would be flat except at the position of string and develops angular defect. In TGD Universe this configuration is not however physical.

a) The absolute minimization of Kähler action requires that the positive Kähler magnetic action of a topologically condensed string must be somehow compensated and the only manner to achieve this is that the strings develop Kähler charges giving rise to a radial Kähler electric fields whose combined action compensates the Kähler magnetic action of the string.

b) Since the net inertial energy in the most elegant TGD Universe must cancel in the length scale of large voids, cosmic string has an enormous (Kähler) energy, In particular, the gravitational mass of the strings deduced from the induced metric associated with the Kähler electric field would be by a factor of order  $10^7$  too large. The only manner to avoid paradox is to allow the pairing of strings having having opposite inertial energy and radial Kähler electric fields of opposite sign. A slight matter antimatter asymmetry is necessary since the Kähler electric fields of two strings with exactly the same magnitude would sum to that of a line dipole.

The pairing must be rather precise so that strings form a coiled structure geometrically analogous to a DNA double helix. This structure could contract to a point at the limit  $a \rightarrow 0$  for  $M_+^4$  option. One could say that two cosmic strings, whose inertial energies are of opposite sign and of equal magnitude are created from vacuum at or shortly after the moment of big bang. Of course this could occur also later. For  $M^4$  option the evolution before the moment of big bang could be preceded by a gravitational collapse and one would have a mirror pair of evolutions. Even a sequence of them making up a temporal mirror hall is possible if the reduction of cosmological constant during cosmic evolution initiates gravitational collapse of the space-time sheet containing the strings at some moment. p-Adic fractality and the fact that the evolution of stars ends with a collapse support this view.

Depending on the character of the fermionic vacuum of strings, one can imagine two mechanisms for the reduction of  $m_I/m_{gr}$  ratio. For the conventional fermionic vacuum inertial mass remains as such and gravitational mass increases. For the non-conventional vacuum  $m_I$  is reduced and  $m_{gr}$  remains unchanged. Galactic rotation curves favor  $T_{gr} \sim 1/R^2$ , which suggests that the reduction of  $m_I/m_{gr}$  is achieved by the reduction of  $m_I$  rather

than growth of  $m_{gr}$ . Despite this both options deserve a more detailed consideration.

#### 4.4 Reduction of the $m_I/m_{gr}$ ratio as a vacuum polarization effect?

The fact that cosmic strings are not small perturbations of vacuum extremals could be seen as a support for the view that the string vacua are conventional so that both fermions and anti-fermions have positive inertial energy and  $m_{gr} = m_I$  holds true for them. Let  $X_{I/II}^4$  be nearly vacuum extremal space-time sheets of opposite time orientation containing strings I and II and correspond to un-conventional phase vacua which are phase conjugates of each other. Since  $X_{I/II}^4$  can carry only a positive/negative fermion number,  $X_I^4$  and  $X_{II}^4$  must be created from the vacuum as a phase conjugate pair with opposite fermion numbers. Matter antimatter asymmetry would result from the vacuum polarization of  $X_{I/II}^4$  in the immediate vicinity of strings generating fermion/antifermion number and gravitational mass of magnitude  $\sim 10^7 m_I$ . As found, the increase of  $T_{gr}$  to  $T_{gr} \sim 1/G$  is not favored by the galactic rotation curves.

#### 4.5 Generation of ordinary matter via Hawking radiation?

The second option is that the string vacua are non-conventional so that fermions and anti-fermions have opposite energies inside them. In this case the strings can reduce their inertial masses by the analog of Hawking radiation involving the generation of fermion anti-fermion pairs, whose second member remains inside string. Assume that the vacuum of the space-time sheet  $X^4$  containing phase conjugate strings I and II, corresponds to the vacuum of either string. String I ( $E > 0$ ) emits positive energy fermions and develops inside it a density of negative energy anti-fermions (fermion number increases) so that the inertial mass density is reduced. String II ( $E < 0$ ) emits negative energy anti-fermions and develops inside it a density of positive energy fermions. The signs of the fermion number and Kähler charge of the string correlate.

This "Hawking radiation" could generate at least part of the visible matter. The splitting of cosmic strings followed by a "burning" of the string ends provides a second manner to generate visible matter. Fermions and negative energy anti-fermions dominate the energy density at the space-time sheet containing strings and strings themselves contain dominantly

negative energy fermions and positive energy anti-fermions. This explains the effective absence of antimatter.

The conservation of magnetic flux implies that the reduction of Kähler energy leads to the thickening of the strings and they become Kähler magnetic flux tubes. As far as net fermion and anti-fermion numbers are considered the exterior region contains positive energy fermions and negative energy anti-fermions (for both of which the sign of fermion number is same!) whereas the string space-time sheets contain negative energy fermions and positive energy anti-fermions. Hence positive energy anti-fermions are effectively absent and in this sense the Universe looks matter-antimatter asymmetric.

Before continuing it must however be emphasized that non-conventional quantization cannot be the only one. The reason is that both kinds of creation operators create states with the same sign of fermion number so that this kind of space-time sheets cannot carry bosons with a vanishing fermion number. The dimension  $D(CP_2)$  of  $CP_2$  projection of the space-time surface serves as a classifier for the asymptotic solutions of field equations for which Lorentz Kähler force vanishes (as a space-time correlate for the absence of dissipation, [D1]). Elementary particles, in particular bosons, correspond to  $CP_2$  type extremals with  $D(CP_2) = 4$ .

For space-time surfaces with a lower-dimensional  $CP_2$  projection the quantization could be always non-conventional. If so, the states would be always many fermion states containing ordinary fermions and what might be called anti-fermion holes. An interesting question is how to experimentally distinguish between fermions and anti-fermion holes: this might be based on the possibility of fermions and anti-fermion holes to accelerate spontaneously without any external energy feed by exchanging energy. Perhaps the reader can develop a convincing argument excluding the interpretation of condensed matter as this kind of phase.

#### 4.5.1 A more detailed picture

A little bit more quantitative picture is obtained by looking more concretely the second quantization of fermions for non-conventional vacuum.

a) Unlike in ordinary quantization both fermionic and anti-fermionic oscillator operators appearing in the second quantized spinor field are either creation - or annihilation operators. There are two fermionic vacua with vanishing vacuum energy and these vacua are phase conjugates of each other.

$$\begin{aligned}
|vac_+\rangle &= \prod_k a_{-k}^\dagger \prod_k b_{+k}^\dagger |0\rangle , \\
|vac_-\rangle &= \prod_k a_{-k} \prod_k b_{+k} |0\rangle .
\end{aligned} \tag{67}$$

Here  $>$  and  $<$  0 refer to positive and negative energy state respectively.

b) One can assume that string I with positive inertial energy corresponds to  $|vac_+\rangle$  and string II to  $|vac_-\rangle$ . For definiteness one can assume that the larger space-time sheet  $X^4$  corresponds to vacuum  $|vac_+\rangle$ . The total vacuum is the tensor product of these vacua.

$$\begin{aligned}
|vac\rangle &= |vac_I\rangle \otimes |vac_0\rangle \otimes |vac_{II}\rangle , \\
|vac_I\rangle &= |vac_0\rangle = |vac_+\rangle , \quad |vac_{II}\rangle = |vac_-\rangle .
\end{aligned} \tag{68}$$

Obviously the selection breaks matter-antimatter symmetry.

c) The generation of Hawking radiation can be modelled by a Hamiltonian, which corresponds to the gravitational energy so that its matrix elements are non-vanishing between states with the same inertial energy. The free part of the Hamiltonian is enough to generate transitions and is of the general form

$$\begin{aligned}
H &= H_- + H_+ + H_a + H_b , \\
H_- &= \sum h_k a_{-k} b_{+k} , \quad H_+ = (H_-)^\dagger = \sum \bar{h}_k a_{-k}^\dagger b_{+k}^\dagger , \\
H_a &= (H_a)^\dagger = \sum \alpha_k a_{-k}^\dagger a_{-k} , \quad H_b = (H_b)^\dagger = \sum \beta_k b_{+k}^\dagger b_{+k} .
\end{aligned} \tag{69}$$

$H_-$  and its conjugate create or annihilate zero energy fermion anti-fermion pairs from vacuum and have vanishing vacuum expectation value.  $H_a$  and  $H_b$  have a non-vanishing vacuum expectation value. It is assumed that the oscillator operators act in the same manner in the state spaces associated with the stringy space-time sheets and the larger space-time sheet containing them. The assumption is consistent with the universality of oscillator operators meaning that same oscillator operators make sense even in different number fields.

d) To see that Hawking radiation can generate the ordinary matter consider the action of operator  $H$  to the vacuum formed as the product of three

vacua. In this case the members of the oscillator operator pairs appearing in  $H$  can act on different vacua and thus induce Hawking radiation. Both  $H_b$  and  $H_-$  are needed in order to generate non-vanishing positive energy fermion- and negative energy anti-fermion numbers in  $X^4$ .

i) The observations

$$H_-|vac_-\rangle = 0 \quad , \quad H_+|vac_+\rangle = 0 \quad (70)$$

help to figure out what parts of  $H$  can reduce the absolute value of the inertial energy of a given string.

ii) The negative inertial energy of string II can be increased by acting by creation operator  $b_+^\dagger$ .  $H_+$  and  $H_b$  contain these operators.  $H_b$  acts on it like  $b_-$  and creates negative energy anti-fermion.  $H_+$  acts on  $|vac_0\rangle$  like  $a_-^\dagger$  and annihilates it or a positive energy fermion radiated from string I.

iii) The positive inertial energy of string I can be reduced by acting by annihilation operator  $b_+$ .  $H_-$  and  $H_b$  contain these operators.  $H_-$  creates to  $|vac_0\rangle$  like  $a_-$  and creates positive energy fermion.  $H_b$  acts on it like  $b_+^\dagger$  and annihilates the ground state or annihilates fermion radiated from string II. What is interesting is that the strings could reduce the absolute values of their inertial energies without generating matter at the larger space-time sheet.

#### 4.5.2 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. The matter at the space-time sheet containing strings in turn consists of positive energy matter and negative energy antimatter and also here same competition would prevail.

This tension brings in mind Yin-Yang principle, the tension between negentropic and entropic tendencies, and even endless fight between Good and Evil, and suggests a general manner to understand the paradoxical aspects of the cosmic and biological evolution.

a) 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 and those containing pairs of 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 antimatter 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.

b) 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.

c) 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.

#### **4.5.3 Creation of matter from vacuum by annihilation of laser waves and their phase conjugates?**

The possibility of negative energy anti-fermions suggests a new energy technology. Photons and their phase conjugates with opposite energies could only annihilate to a pair of positive energy fermion and negative energy anti-fermion. Vacuum could effectively serve as an unlimited source of positive energy and make creation of matter from nothing literally possible. The idea could be tested by allowing laser beams and their phase conjugates to



interact and by looking whether fermions pop out via two-photon annihilation. Fermion-anti-fermion pairs with arbitrarily large fermion masses could be generated by utilizing photons of arbitrarily low energy. The energies of the final state fermions are completely fixed from conservation laws so that it should be relatively easy to check whether the process really occurs. Generalized Feynman rules predict the cross section for the process and it should behave as  $\sigma \propto \alpha^2/m^2$ , where  $m$  is the mass of the fermion so that annihilation to electrons is the best candidate for study. Bio-systems might have already invented intentional generation of matter in this manner. Certainly the possible new energy technology should be applied with some caution in order to not to build a new quasar!

Speaking more seriously, the creation and annihilation of pairs of positive and negative energy space-time sheets would have a change of gravitational mass as its signature so that the process could be detected. In particular, the annihilation of fermions and anti-fermions to pairs of phase conjugate photons would reduce gravitational mass and give rise to antigravity effects.

## 4.6 Cosmic strings and cosmological constant

The study of Einstein's equations for cosmic strings forces the conclusion that cosmological constant is non-vanishing in TGD Universe. p-Adic length scale hypothesis leads to a scenario for the evolution of cosmological constant predicting its recent value correctly. Cosmic strings allow to interpret cosmological constant as characterizing the density of gravitational energy associated with the space-time sheets carrying pairs of positive and negative energy cosmic strings and having a vanishing net Kähler charge. Therefore, contrary to the original beliefs, the models for dark matter based on cosmological constant and cosmic strings are actually equivalent.

### 4.6.1 Cosmological constant for the internal dynamics of strings

In order to understand why cosmological constant is unavoidable at the level of gravitational dynamics in the interior of cosmic strings, one can simplify things by assuming that  $X^2$  in  $X^4 = X^2 \times S_I^2$  is a flat piece  $M^2$  of  $M_+^4$  so that the Einstein tensor has expression

$$G^{\alpha\beta} = \mathbf{R}(S_I^2) - \frac{1}{2}\mathbf{g}R(S_I^2) . \quad (71)$$

where  $R(S_I^2)$  denotes the curvature scalar. The energy density  $G^{tt} = -(1/2)R(S_I^2)$  is negative because of spherical topology. Obviously cosmic strings

correspond to the p-adic length scale  $L(2)$  naturally so that it should be possible to deduce a lower bound for  $\Lambda(2)$  from the requirement that gravitational energy density is non-negative.

There are actually two constraints involved.

a) The first constraint comes from the sum of the energies of matter and antimatter expressible as the energy of Kähler field. One cannot exclude the possibility that for cosmic strings the quantization in fermionic sector is such that the energies both fermions and anti-fermions are either positive or negative. This requires that cosmic strings created in the big bang or possibly later appear in pairs which opposite vacuum energies.

The energy momentum tensor for Kähler field and Einstein tensor can be written as

$$\begin{aligned}\mathbf{T}_K &= \frac{1}{2 \times 16\pi\alpha_K R^4} (\mathbf{g}(M^2) - \mathbf{g}(S^2)) , \\ \mathbf{G} &= -\frac{4}{R^2} \mathbf{g}(M^2) .\end{aligned}\tag{72}$$

Note that the radius of  $S_I^2$  is  $R/4$  for the conventions used.

$\mathbf{T}_K$  can be written as sum of Einstein tensor and metric tensor as

$$\begin{aligned}\mathbf{T}_K &= \frac{1}{16\pi G_{eg}} \mathbf{G} + \hat{\Lambda}_{eg} \mathbf{g} , \\ G_{eg} &= 8R^2 \alpha_K , \\ \hat{\Lambda}_{eg} &= \frac{1}{2R^4 \times 16\pi\alpha_K} .\end{aligned}\tag{73}$$

Note that the ratio  $G_{eg}/G = \frac{8R^2}{G} \alpha_K$  is much larger than one.

The study of simple imbeddings of Maxwell field to  $M^4 \times S_I^2$ , demonstrates that Einstein's equations hold true approximately also more generally in the non-relativistic approximation and the value of  $G_{eg}$  is as above. This raises the possibility that the dynamics of Kähler action could be reflected in phenomena of electro-gravitation and that near vacuum extremals could be seen as a limit at which electro-gravitational coupling strength becomes very large.

There would be thus two "gravitations": one for the sum and one for the difference of energies of matter and antimatter. The consistency with the existing theory requires an approximate separate conservation of these energies meaning that the annihilation of matter and antimatter can be neglected.

TGD based models for the asymptotic cosmology and the asymptotic state of star rely on this assumption.

b) Gravitational energy tensor can be written as a sum of Einstein tensor and metric tensor

$$\mathbf{T}_{gr} = \frac{1}{16\pi G} \mathbf{G} + \Lambda(2)\mathbf{g} . \quad (74)$$

c) The basic constraint comes from the requirement that irrespective of the option chosen for the fermionic quantization one has

$$E_{gr} \geq E_K , \quad (75)$$

where one has

$$\begin{aligned} E_{gr} &= -\frac{1}{16G} + \hat{\Lambda}(2) \frac{\pi R^2}{4} , \\ E_K &= -\frac{1}{16G_{ge}} + \hat{\Lambda}_{ge} \frac{\pi R^2}{4} = \frac{1}{4 \times 16\alpha_K R^2} . \end{aligned} \quad (76)$$

The lower bound means that the two terms in gravitational energy nearly cancel each other since the right hand side is of order  $10^{-7}$  as compared to the left hand side. One has

$$\hat{\Lambda}(2) \geq \frac{1}{16R^4} \left[ \frac{16R^2}{G} + \frac{1}{\alpha_K} \right] . \quad (77)$$

For the minimal value of  $\Lambda(2)$  gravitational and inertial energies are identical. This corresponds to the situation in which negative energy contribution to the inertial energy vanishes. This situation can result in two manners. Either antimatter is absent or fermionic quantization is performed in the standard manner. The latter option fixes the value of  $\hat{\Lambda}(2)$  completely.

Strings with conventional fermionic vacua can emit positive energy fermions during later stages of evolution: this reduces the energy density of the string. In the case that the stringy fermionic vacuum is non-conventional, the string can generate fermion anti-fermion pairs during later phases of cosmic evolution such that the negative energy member of the pair remains inside string and reduces its energy density (note that fermion number increases!). The reduction of the energy density means a thickening of the string since flux quantization condition must be satisfied. Energy density behaves as  $1/S$  during this process.

### 4.6.2 p-Adic evolution of cosmological constant

The evolution of the cosmological constant  $\Lambda$  is different at each space-time sheet, and the value of  $\Lambda$  is determined by the p-adic length scale size of the space-time sheet according to the formula  $\Lambda(k) = \Lambda(2) \times (L(2)/L(k))^2$  derived in the [D5] from the requirement that gravitational energy as difference of inertial energies and matter and antimatter (or vice versa) is non-negative. Since cosmological expansion forces both strings to become very thin as the initial moment is approached,  $\Lambda(k)$  must decrease during cosmological evolution of the void and increase again during the possibly occurring contraction phase. The reduction of the value of  $\Lambda$  below critical value might initiate the phase of contraction. The value of  $\Lambda(k)$  at the space-time sheet at which strings are condensed is smaller than for cosmic strings since the thickness of the string characterizes the value of  $\Lambda$ .

In standard physics context piecewise constant cosmological constant would be naturally replaced by a cosmological constant behaving like  $1/a^2$  as a function of cosmic time. p-Adic prediction is consistent with the recent study [25] according to which cosmological constant has not changed during the last 8 billion years: the conclusion comes from the redshifts of supernovae of type I<sub>a</sub>. If p-adic length scales  $L(k) = p \simeq 2^k$ ,  $k$  any positive integer, are allowed, the finding gives the lower bound  $T_N > \sqrt{(2)/(\sqrt{2} - 1)} \times 8 = 27.3$  billion years for the recent age of the universe.

Now Brad Shaefer from Louisiana University has studied the red shifts of gamma ray bursters up to a red shift  $z = 6.3$ , which corresponds to a distance of 13 billion light years [26], and claims that the fit to the data is not consistent with the time independence of the cosmological constant. In TGD framework this would mean that a phase transition changing the value of the cosmological constant must have occurred during last 13 billion years.

### 4.6.3 Cosmological constant for the Kähler neutral space-time sheets carrying pairs of strings

There is a strong temptation to relate the presence of the cosmological constant in the model for topological condensation in terms of constant density of  $U(1)$  gauge charge (not Kähler charge for vacuum extremals).

a) In case of Kähler charge this would lead to a modification of the previous ansatz for the space-time sheet containing strings of opposite inertial energies by adding to  $u = \cos(\Theta)$  a term which is linear in coordinate  $\rho$ :  $u \rightarrow u + k_1 \frac{\rho}{\rho_0}$ . This ansatz does not however satisfy field equations even

approximately.

b) One can however consider vacuum extremals with similar structure imbedded to  $M^4 \times Y^2$ ,  $Y^2$  could be  $S_{II}^2$  or a more general Lagrange submanifold of  $CP_2$  so that field equations reduce to boundary conditions stating that gravitational four-momentum does not leak out from boundaries. Also in this case cosmological constant would correspond to a presence of constant  $U(1)$  gauge charge density.

c) The ordinary gravitational potential energy of a co-moving volume decreases as  $E_{gr} \propto M^2(L(k))/L(k)$  as a function of the p-adic scale, whereas cosmological constant varying as  $1/L(k)^2$  contributes to the gravitational energy a positive term  $E_\Lambda \propto L(k)$  implying  $V_{gr} \propto L(k)$  and  $E_{tot} \propto L(k)$ . The prediction that the energy of the space-time sheet is proportional to its size is just what has been observed to hold true for galactic dark matter distribution. This suggest that the dark matter is due to Kähler neutral space-time sheets containing pairs of cosmic strings and cosmological constant characterizes the density of the dark matter decreasing as  $1/T^2(k)$  and on the average as  $1/a^2$  as a function of cosmic time. Thus the original idea about cosmic strings as the source of dark matter would be basically correct.

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