Cosmic Strings

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Abstract

Cosmic strings belong to the basic extremals of the Kähler action. The upper bound for string tension of the cosmic strings is $T \simeq .5 \times 10^{-6}/G$ and in the same range as the string tension of GUT strings and this makes them very interesting cosmologically although TGD cosmic strings have otherwise practically nothing to do with their GUT counterparts.

1. Basic ideas

The understanding of cosmic strings has developed only slowly and has required dramatic modifications of existing views.

a) Zero energy ontology implies that the inertial energy and all quantum numbers of the Universe vanishes and physical states are zero energy states decomposing into pairs of positive and negative energy states. Positive energy ontology is a good approximation under certain assumptions.

b) Dark matter hierarchy whose levels are labelled by gigantic values of gravitational Planck constant associated with dark matter is second essential piece of the picture.

c) The identification of gravitational four-momentum as the Noether charge associated with curvature scalar looks in retrospect completely obvious and resolves the long standing ambiguities. This identification explains the non-conservation of gravitational four-momentum which is in contrast with the conservation of inertial four-momentum and implies breaking of Equivalence Principle. There are good reasons to believe that this breaking can be avoided for elementary particles and hadronic strings.

d) The gravitational energy of string like objects $X^2 \times Y^2 \subset M^4 \times CP_2$ corresponds to gravitational string tension $T_{gr} = (1-g)/4G$ which is negative for $g > 1$. The string tension is by a factor of order 10^7 larger than the inertial string tension. This leads to the hypothesis that $g > 1$ "big" strings in the centers of large voids generate repulsive gravitational force driving $g = 1$ galactic strings to the boundaries of the voids. If the total gravitational mass of strings inside voids vanishes, the breaking of Equivalence Principle occurs only below the size scale of the void.

e) The basic question whether one can model the exterior region of the topologically condensed cosmic string using General Relativity. The exterior metric of the cosmic string corresponds to a small deformation of a vacuum extremal. The angular defect and surplus associated with the exterior metrics extremizing curvature scalar can be much smaller than assuming vacuum Einstein's equations. The conjecture is that the exterior metric of $g = 1$ galactic string conforms with the Newtonian intuitions and thus explains the constant velocity spectrum of distant stars if one assumes that galaxies are organized to linear structures along long strings like pearls in a necklace.

2. Critical and over-critical cosmologies involve accelerated cosmic expansion

In TGD framework critical and over-critical cosmologies are unique apart from single parameter telling their duration and predict the recently discovered accelerated cosmic expansion. Critical cosmologies are naturally associated with quantum critical phase transitions involving the change of gravitational Planck constant. A natural candidate for such a transition is the increase of the size of a large void as galactic strings have been driven to its boundary. During the phase transitions connecting two stationary cosmologies (extremals of curvature scalar) also determined apart from single parameter, accelerated expansion is predicted to occur. These transitions are completely analogous to quantum transitions at atomic level.

The proposed microscopic model predicts that the TGD counterpart of the quantity $\rho + 3p$ for cosmic strings is negative during the phase transition which implies accelerated expansion. Dark energy is replaced in TGD framework with dark matter indeed predicted by TGD and its fraction is .74 as in standard scenario. Cosmological constant thus characterizes the density of dark matter rather than energy in TGD Universe.

The sizes of large voids stay constant during stationary periods which means that also cosmological constant is piecewise constant. p-Adic length fractality predicts that Λ scales as $1/L^2(k)$ as a function of the p-adic scale characterizing the space-time sheet of void. The order of magnitude for 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.

3. Cosmic strings and generation of structures

a) In zero energy ontology cosmic strings must be created from vacuum as zero energy states consisting of pairs of strings with opposite time orientation and inertial energy.

b) The counterpart of Hawking radiation provides a mechanism by which cosmic strings can generate ordinary matter. The splitting of cosmic strings followed by a "burning" of the string ends provides a second manner to generate visible matter. Matter-antimatter symmetry would result if antimatter is inside cosmic strings and matter in the exterior region.

c) Zero energy ontology has deep implications for the cosmic and ultimately also for biological evolution (magnetic flux tubes paly a fundamental role in TGD inspired biology and cosmic strings are limiting cases of them). 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 each other. This resolves paradoxes created by gravitational self-organization contra second law of thermodynamics. So called super-canonical matter at cosmic strings implies large p-adic entropy resolves the well-known entropy paradox.

d) p-Adic fractality and simple quantitative observations lead to the hypothesis that 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 cosmic strings 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...

4. Cosmic strings, gamma ray bursts, and supernovae

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.

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 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. The fact that all nuclei are fully ionized Z^0 ions, the Z^0 charge unbalance caused by the ejection of neutrinos, and the radial compression make the effect extremely strong so that there are hopes to understand the observed incredibly high polarization of 80 ± 20 per cent.

TGD suggests the identification of particles of mass $m \simeq 2m_e$ accompanying dark matter as lepto-pions 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.

1 Introduction

Cosmic strings belong to the basic extremals of the Kähler action. These cosmic strings have nothing to do with the cosmic strings of GUTS [50] but their string tension $T \simeq .52 \times 10^{-6}/G$ happens to be in the same range as that for the GUT strings and this makes them very interesting cosmologically. Indeed, string like objects play a 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.

The physical interpretation of strings depends on the principle assumed to select the preferred extremals as generalized Bohr orbits. There are some objections against absolute minimization (call this option $P1$) and the number theoretically favored principle selects preferred extremals as surfaces minimizing ($P2$) or maximizing ($P3$) the absolute value of Kähler action separately for each space-time region where the action has a definite sign [E2]. $P2$ and $P3$ dual of each other are symmetric under exchange of electric and magnetic fields unlike absolute minimization. Both $P2$ and $P3$ can be acceptable options since it is 3-surface which is fundamental notion whereas space-time surface is a derived concept. $P2$ would represent a conservative view about future and past minimizing gradients whereas $P3$ would tend to exaggerate gradients and give more dramatic view about future and past. It would depend on situation which of the principles gives best space-time correlates for the quantum theory.

1.1 Various strings

TGD predicts two basic types of strings.

1. The analogs of hadronic strings correspond to deformations of vacuum extremals carrying non-vanishing induced Kähler fields. p-Adic thermodynamics for super-canonical quanta condensed on them with additivity of mass squared yields without further assumptions stringy mass formula. These strings are associated with various fractally scaled up variants of hadron physics.

2. Cosmic strings correspond to homologically non-trivial geodesic sphere of CP_2 (more generally to complex sub-manifolds of CP_2) and have a huge string tension. These strings are expected to have deformations with smaller string tension which look like magnetic flux tubes with finite thickness in M^4 degrees of freedom. The gravitational string tension defined by the Einstein tensor of the induced metric is $(1-g)/4G$ and therefore gigantic and negative for $g > 1$.

1.2 TGD based model for cosmic strings

The model for cosmic strings has forced to question all cherished assumptions including positive energy ontology, Equivalence Principle, and positivity of gravitational energy.

1.2.1 Zero energy ontology and cosmic strings

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

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

2. In long enough length and time scales Kähler action per volume must vanish so that the idealization of cosmology as a vacuum extremal becomes possible and there must be some mechanism compensating the positive action of the free cosmic strings. The mechanism need not be local.

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

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

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

1.2.2 Failure of Equivalence Principle for cosmic strings

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

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

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

It is however possible that in sufficiently long length scales the gravitational energies of $g > 1$ and and $g \leq 1$ strings sum up to zero so that cosmic strings would make them effectively invisible and Equivalence Principle would hold true. This could happen in length scales longer than the size $L \sim 10^8$ ly of large voids [54].

1.2.3 Topological condensation of cosmic strings

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

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

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

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

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

One cannot assume that the exterior metric of the galactic $g = 1$ strings is the one predicted by assuming $G = 0$ in the exterior region. This would mean that metric decomposes as $g = g_2(X^2) + g_2(Y^2)$. $g(X^2)$ would be flat as also $g_2(Y^2)$ expect at the position of string. The resulting angle defect due to the replacement of plane Y^2 with cone would be large and give rise to lense effect of same magnitude as in the case of GUT cosmic strings. This lensing has not been observed.

The constant velocity spectrum for distant stars of galaxies and the fact that galaxies are organized along strings suggests that these string generate in a good approximation Newtonian potential. This potential predicts constant velocity spectrum with a correct value velocity.

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

1.2.4 Dark energy is replaced with dark matter in TGD framework

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

1. The gigantic value of gravitational Planck constant implies that dark matter makes TGD Universe a macroscopic quantum system even in cosmological length scales. Astrophysical systems become stationary quantum systems which participate in cosmic expansion only via quantum phase transitions increasing the value of gravitational Planck constant. Critical cosmologies, which are determined apart from a single parameter in TGD Universe, are natural during all quantum phase transitions, in particular the phase transition periods increasing the size of large voids and having interpretation in terms of an increase of gravitational Planck constant. Cosmic expansion is predicted to be accelerating during these periods. The mere criticality requires that besides ordinary matter there is a contribution $\Omega_\Lambda \simeq .74$ to the mass density besides visible matter and dark matter.

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

1.2.5 The values for the TGD counterpart of cosmological constant

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

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

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

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

1.3 Correlation between super-novae and cosmic strings

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

1. A correlation between supernovae and gamma ray bursts was observed.

2. 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 [D4] 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 (flux tube carries also em field but could carry only Z^0 charge). 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 ± 20 per cent [36].

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.

2 General vision about topological condensation of cosmic strings

In this section the basic properties of free cosmic strings are discussed and a general vision about topological condensation of cosmic strings is proposed. In the later sections the vision is developed at a more quantitative level.

2.1 The relationship between inertial and gravitational masses

The understanding of the relationship between inertial and gravitational four-momentum has turned out to be a highly non-trivial challenge. The most straightforward identification of inertial and gravitational charges would be as isometry charges associated with Kähler action and curvature scalar. Obviously Equivalence Principle in strong sense is not satisfied without additional assumptions and the attempt to save Equivalence Principle has yielded a lot of arguments and scenarios. As a rule it has turned out that something in every promising interpretation goes eventually somehow wrong. These interpretational difficulties suggest that that some cherished assumption might be wrong. In the recent case Equivalence Principle might be this kind of cherished assumption.

An empirical fact is that gravitational four-momentum is not conserved in cosmological length scales whereas the inertial four-momentum is conserved. Accelerated cosmic expansion is second empirical fact for which one explanation is in terms of positive cosmological constant. One can ask whether this gravitational dark energy has any inertial counterpart at all so that Equivalence Principle would be indeed violated as TGD without any additional assumptions indeed predicts. In this framework dark inertial energy could be seen as a hopeless attempt to save Equivalence Principle. Somewhat ironically, it turns out that giving up Equivalence Principle below the size scale L of large voids leads in TGD framework to the identification of dark energy as dark matter and there is no need to introduce cosmological constant.

The positive sign of gravitational energy is also a cherished assumption and zero energy ontology encourages to consider the possibility that it does not hold true. Indeed, the gravitational energy for string like objects $X^2 \times Y^2 \subset M^4 \times CP_2$ is negative if Y^2 has genus $g > 1$ if gravitational energy is identified as Einstein tensor for the induced metric.

A further empirical fact is that the expansion of the Universe accelerates. The observation that the almost unique critical and over-critical cosmologies allowed by TGD predict accelerated expansion inspires the idea that acceleration is associated with quantum critical phase transitions increasing gravitational Planck constant and hence also the size of large voids. The task is to identify the detailed mechanism. It could be that the presence of negative gravitational masses induces repulsion on both positive and negative energy matter and in this manner causes the accelerated expansion.

2.1.1 Four-momenta in the parton level formulation and 4-D formulation

The parton level formulation of TGD in terms of light-like 3-surfaces as an almost topological QFT using Chern-Simons action implies also the non-conservation of classical four-momentum identified as Noether charge at parton level although mass squared is conserved [C1, C2]. Four-momentum is conserved at the level of S-matrix since the formulation of the theory is translationally invariant.

In 4-D formulation elementary particles can be idealized as CP_2 type vacuum extremals. The inertial four-momentum associated with Kähler action vanishes since the energy momentum tensor vanishes. Topological condensation generates the inertial mass assignable to the light-like wormhole throats. Gravitational four-momentum is non-vanishing and light-like and conserved if M^4 projection is light-like geodesic. Thus the counterpart of dark energy appears already at elementary particle level. It is quite possible that the average value of gravitational four-momentum corresponds to that for inertial four-momentum so that Equivalence Principle would hold true at elementary particle level.

A further delicacy comes from the identification of fermions as light-like wormhole throats associated with CP_2 type vacuum extremals topologically condensed at space-time sheets with positive or negative time orientation and of bosons as pairs of wormhole throats associated with wormhole contacts connecting positive and negative energy space-time sheets. For elementary particles the net inertial four-momenta need not vanish in general.

For a given zero energy state the inertial four-momentum can be identified as the time average of the Noether momentum of positive/negative energy space-time sheets [F2]. All conserved Noether charges are assigned to the Kähler action. If Kähler action is identifiable as the effective action defined by the Dirac determinant associated with the modified Dirac action [C2], the formulation reduces completely to the parton level. An open question is whether this really occurs and whether it is necessarily needed.

At microscopic level inertial four-momenta can be can be assigned with the individual elementary particles appearing as incoming and outgoing lines in the generalized Feynman diagrams

[C1, C2]. Poincare invariance at the level of S-matrix requires that the extremals of Kähler action representing incoming and outgoing lines must be such that inertial 4-momenta and other Noether quantum numbers are conserved at the vertices.

2.1.2 Zero energy ontology

Robertson-Walker cosmologies correspond to vacua with respect to inertial energy and in fact with respect to all quantum numbers. They are not vacua with respect to gravitational charges defined as Noether charges associated with the curvature scalar. Also more general imbeddings of Einstein's equations are typically vacuum extremals with respect to Noether charges assignable to Kähler action since otherwise one ends up with conflict between imbeddability and dynamics. This suggests that physical states have vanishing net quantum numbers quite generally. The construction of quantum theory [C1, D3] indeed leads naturally to zero energy ontology stating that everything is creatable from vacuum.

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

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

2.1.3 Zero energy ontology and Equivalence Principle

Consider now Equivalence Principle from the point of zero energy ontology.

1. If Equivalence Principle holds true in strict sense, vacuum extremals can provide only some kind of cognitive representation for zero energy states allowing to assign to each component of state vacuum extremal whose properties correlate with those of the component. Equivalence Principle would generalize not only to isometry charges but to much more general context. Unfortunately the sole purpose of this representation seems to be that it makes it easy to discover the basic predictions of TGD. Purely mathematical considerations also suggest strongly that actual space-time sheets are always small deformations of vacuum extremals.

2. If Equivalence Principle in strict form is given up, small deformations of vacuum extremals are very natural candidates for space-time sheets containing matter having non-vanishing inertial energy and acting as gravitational energy at the larger space-time sheet. It turns out that Equivalence Principle can hold true for elementary particles, for light string like objects, and also for cosmic strings in length scales longer than the size of large voids.

2.2 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

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

Outside the light cone the line element is given

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

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

$$\begin{aligned} \theta &= \frac{\pi}{2} \ , \\ \phi &= f(r) \ . \end{aligned} \qquad (3)$$

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

$$ds^2 = da^2 - a^2(\frac{1}{1+r^2} + r^2 f_{,r}^2) dr^2 \ . \qquad (4)$$

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^α gives

$$\begin{aligned} T^\alpha_{,\alpha} &= 0 \ , \\ T^\alpha &= T g^{\alpha\beta} m^0_{,\beta} \sqrt{g} \ , \\ T &= \frac{1}{8\alpha_K R^2} \simeq .52 \times 10^{-6} \frac{1}{G} \ . \end{aligned} \qquad (5)$$

The numerical estimate $TG \simeq .52 \times 10^{-6}$ for the string tension is upper bound and corresponds to a situation in which the entire area of S^2 contributes to the tension. It has been obtained using $\alpha_K/104$ and $R^2/G = 2.5 \times 10^7 G$ given by the most recent version of p-adic mass calculations (the earlier estimate was roughly by a factor 1/2 too small due to error in the calculation [C5, D3]). The string tension belongs to the range $TG \in [10^{-6} - 10^{-7}]$ predicted for GUT strings [50]. WMAP data give the upper bound $TG \in [10^{-6} - 10^{-7}]$, which does not however hold true in the recent case since criticality predicts adiabatic spectrum of perturbations as in the inflationary scenarios.

The non-vanishing components of energy current are given by

$$\begin{aligned} T^a &= TUa \ , \\ T^r &= -T\frac{r}{U} \ , \\ U &= \sqrt{1 + r^2(1+r^2) f_{,r}^2} \ . \end{aligned} \qquad (6)$$

The equations of motion give

$$U = \frac{r}{\sqrt{r^2 - r_0^2}} \ , \qquad (7)$$

or equivalently

$$\phi_{,r} \quad = \quad \frac{r_0}{r\sqrt{(r^2-r_0^2)(1+r^2)}} \quad , \tag{8}$$

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

$$\phi_{,r} \quad = \quad \frac{r_0}{\sqrt{r^2+r_0^2}r\sqrt{1-r^2}} \quad . \tag{9}$$

In the region inside the light cone, where the conditions

$$r_0 \quad << \quad r << 1 \tag{10}$$

hold, the solution has the form

$$\begin{aligned} \phi(r) &\simeq \phi_0 + \frac{v}{r} \quad , \\ v &= \frac{r_0}{\sqrt{1+r_0^2}} \quad , \end{aligned} \tag{11}$$

corresponding to the linearized equations of motion

$$f_{,rr} + \frac{2f_{,r}}{r} \quad = \quad 0 \quad , \tag{12}$$

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

$$\omega \quad \simeq \quad \frac{v}{r_M} \tag{13}$$

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 ϕ 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 ϕ 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

$$J^r \quad = \quad Tr^2a \quad . \tag{14}$$

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

$$J = \frac{Tr^2a^2}{2} = \frac{Tr_M^2}{2} \ . \tag{15}$$

This angular momentum is of the same order of magnitude as the angular momentum of a typical galaxy [18].

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

$$\begin{aligned} r_M &= vm^0 \ , \\ v &= \frac{r_0}{\sqrt{1+r_0^2}} \ . \end{aligned} \tag{16}$$

From the expression of the energy density of the string

$$\begin{aligned} T^a &= T\frac{ar}{\sqrt{r^2-r_0^2}} \ , \\ T &= \frac{1}{8\alpha_K R^2} \ , \end{aligned} \tag{17}$$

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 2π in GRT so that there seems to be no conflict with General Relativity (unlike in the original 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

$$E = T\sqrt{(r_1^2-r_0^2)}a = T\sqrt{\delta r_M^2} \ . \tag{18}$$

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 ϕ from the integral

$$\Delta\phi = \sqrt{\frac{r_0^2}{1+r_0^2}}\int_{r_0}^{\infty} dr\frac{1}{r\sqrt{(r^2-r_0^2)(1+r^2)}} \ . \tag{19}$$

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

2.3 What happens in the topological condensation of cosmic strings?

The crucial question is what happens in the topological condensation of cosmic strings.

2.3.1 Failure of Equivalence Principle

The basic hypothesis is that exterior metrics correspond to small deformations of vacuum extremals. Hence vacuum extremals give good approximations for the exterior metrics. This can be justified if one accepts as a fact that gravitational and inertial masses assignable as Noether charges to the curvature scalar and Kähler action are not identical and their difference corresponds to what might be called dark gravitational energy not however identifiable as dark energy as it turns out.

The positivity of gravitational energy is second cherished principle. The possibility of negative inertial energies means the possibility of negative gravitational energies but this does not change the situation since the solutions of with negative time orientation are temporal mirror images of those with positive time orientation. What is important is that for positive arrow of time gravitational mass of the simplest string like objects is negative.

2.3.2 What is the gravitational mass of cosmic string?

In the case of positive energy cosmic strings it is easy to find the imbedding of the almost everywhere flat exterior metric of cosmic string with 1-dimensional CP_2 projection. This however predicts lense effect to be a signature of cosmic strings. There is no experimental evidence for this.

The assumption hitherto has been that the gravitational mass appearing in the expression for the gravitational field of the cosmic string equals to its inertial mass. If one gives up Equivalence Principle and assumes that the gravitational mass in the lowest order approximation corresponds to the mass defined by the Noether current associated with Einstein's action for cosmic string, the situation changes.

The Einstein tensor of cosmic string has the structure $-g^{\alpha\beta}(X^2)R(Y^2)/2 - g^{\alpha\beta}(Y^2)R(X^2)/2$. From $T = -G$ the string tension is given by

$$T_{gr} \equiv \frac{dM_{gr}}{dl} = \frac{1}{16\pi G}\int R(Y^2)\sqrt{g_2}d^2y$$

Gauss-Bonnet theorem states that the integral of the curvature scalar which is twice the Gaussian curvature equals to $4\pi(1-g)$. Therefore one has

$$T_{gr} = \frac{1-g}{4G} \tag{20}$$

so that $g > 1$ strings would have negative gravitational energy.

Something happens to the string tension in topological condensation.

1. If ordinary wormhole contacts are in question, only a small increase of the string tension is expected. Since wormhole contacts have interpretation as bosons this increase should correlate with the physical state of the cosmic string and by quantum classical correspondence should be identifiable as the contribution of Kähler action to the string tension so that one would have an interpretation very similar to that in GRT. The gravitational mass at the larger space-time sheet would thus include also the contribution of the inertial mass. In the case $g = 1$ strings - about which hadronic strings are one example - gravitational mass would be inertial mass. A little argument shows that for CP_2 type extremals gravitational and inertial masses could be also identified so that only $g \neq 1$ strings break Equivalence Principle.

   This assumption is supported by the fact that the string tension associated with Kähler action explains the velocity spectrum of distant stars around galaxies if galaxies are like strings in a pearl organized around long strings and generate gravitational field resembling that associated with Newtonian approximation. This would be obtained for $g_{eff} = 1$ for galactic cosmic strings.

2. One can consider also the possibility that topological condensation generates "stringy" wormhole contacts reducing to wormhole contacts at the level of S^2 and extending along the string. This option is not favored by stability considerations but one can also consider drilling holes to S^2. Each of them would corresponds effectively to $\Delta g = 1/2$ so that g must be replaced with half-integer value g_{eff} in the basic formula.

   In topological condensation $\Delta g \geq 1/2$ is generated and the angle defect is not smaller than 2π $(1/2-g)2\pi$. For spherical topology the purely gravitational string tension would becomes zero by the presence of two stringy wormhole contacts or by two holes in S^2. Two stringy wormhole contacts gives vanishing gravitational string tension in the case of spherical topology. For $g = 1$ with single wormhole contact angle surplus equals to π. For $g \geq 2$ one has angle surplus larger than 2π.

2.3.3 Equivalence Principle in length scales longer than size of large void

The average density of negative gravitational energy can be easily estimated. The average length of negative energy cosmic string inside the large void is proportional to the radius $R(a)$ of the void proportional to cosmic proper time: $R(a)/R_0 = a/a_0$ in average sense. If the length of the straight string equals to the diameter of the void the magnitude of the gravitational mass equals to $M(a) = (1-g)R(a)/2G$ which the mass of a black-hole with same radius. This gives

$$\begin{aligned} \rho_-(a) &\geq \frac{M(a)}{Vol(a)} = (1-g)\rho_{cr}g_{aa}(\frac{a_0}{R_0})^2 \ , \\ M(a) &= (1-g)\frac{R(a)}{2G} \ , \ Vol(a) = \frac{4\pi R^3(a)}{3} \ . \end{aligned} \tag{21}$$

If one assumes Equivalence Principle in length scales longer than the size of the large void the negative gravitational mass of $g > 1$ string in the center of the big string void could be compensated by the positive gravitational mass of galactic $g \leq 1$ galactic strings. $g = 0$ galactic strings would be characterized by very high velocity of distant stars and are not a plausible candidate. The total length of these strings would be by a factor $T_{big}/Tgal = (g-1)/4GT_{gal}$ longer than the length of the big cosmic string if galactic strings have same string tension T_{gal}. The conclusion would be that the net contribution of purely gravitational energy would vanishes and Λ would have nothing to do with it.

The preceding considerations suggest that the stringy gravitational masses cancel above the length scale of large voids for positive energy space-time sheets. That gravitational mass density is however non-vanishing for Robertson-Walker cosmologies for which inertial mass density vanishes. This means that the gravitational masses in question correspond to inertial masses at the topologically condensed space-time sheets.

2.3.4 TGD cosmic strings are consistent with the fluctuations of CMB

GUT cosmic strings were excluded by the fluctuation spectrum of the CMB background [52]. In GRT framework these fluctuations can be classified to adiabatic density perturbations and isocurvature density perturbations. Adiabatic density perturbations correspond to overall scaling of various densities and do not affect the vanishing curvature scalar. For isocurvature density fluctuations the net energy density remains invariant. GUT cosmic strings predict isocurvature density perturbations while inflationary scenario predicts adiabatic density fluctuations.

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

2.4 Mechanism of accelerated expansion in TGD Universe

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

2.4.1 How accelerated expansion results in standard cosmology?

The accelerated of cosmic expansion means that the deceleration parameter

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

is negative. For Robertson-Walker cosmologies one has

$$\begin{aligned} H^2 &\equiv (\frac{da/ds}{a})^2 = \frac{8\pi G\rho + \Lambda}{3} - K/a^2, \quad K = 0, \pm 1 \ , \\ 3\frac{d^2a/ds^2}{a} &= \Lambda - 4\pi G(\rho + 3p) \equiv -4\pi G(1+3w)\rho \ . \end{aligned} \tag{22}$$

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

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

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

$$-G^{\alpha\beta} - \Lambda g^{\alpha\beta} = 8\pi G T^{\alpha\beta} \tag{23}$$

it is clear that the introduction of a positive cosmological constant could be interpreted by saying that for gravitational vacuum carries energy density equal to $\Lambda/8\pi$ and negative pressure. The negative gravitational pressure would induce the acceleration. Cosmological term at the level of field equations could be also interpreted by saying that Einstein's equations hold true in the original sense but that energy momentum tensor contains besides the density of inertial mass also a positive density of purely gravitational mass: $T \rightarrow T + \Lambda g$ so that Equivalence Principle fails. Since cosmological constant means effectively negative pressure $p = -\Lambda/8\pi$ the introduction of the cosmological constant means the effective replacement $\rho + 3p \rightarrow \rho + 3p - 2\Lambda/8\pi)$. In the so called $\Lambda - CDM$ model [51] the densities of dark energy, ordinary matter, and dark matter are assumed to sum up to critical mass density $\rho_{cr} = 3/(8\pi g_{aa} G a^2)$. The fraction of dark matter density is deduced to be $\Omega_\Lambda = .74$ from mere criticality.

2.4.2 Critical cosmology predicts accelerated expansion

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

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

$$3\frac{d^2a/ds^2}{a} = \Lambda - 4\pi G(\rho + 3p) \ . \tag{24}$$

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

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

$$q \equiv -a\frac{d^2a/ds^2}{(da/ds)^2} \ . \tag{25}$$

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

1. String dominated cosmology

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

$$g_{aa} \equiv (ds/da)^2 = 1 - K_0 \ . \tag{26}$$

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

2. Critical cosmology

Critical cosmology with flat 3-space corresponds to

$$\begin{aligned} g_{aa} &= 1 - K \ , \\ K &\equiv \frac{K_0}{1-u^2} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{27}$$

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

$$q = -K_0\frac{K_0u^2}{1-u^2-K_0} < 0 \ , \tag{28}$$

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

$$\frac{dH/ds}{H^2} = -(1+q) \ , \tag{29}$$

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

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

3. Stationary cosmology

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

$$\begin{aligned} g_{aa} &= \frac{1-2x}{1-x} \ , \\ x &= (\frac{a_0}{a})^{2/3} \ . \end{aligned} \tag{30}$$

The deceleration parameter

$$q = \frac{1}{3}\frac{x}{(1-2x)(1-x)} \ . \tag{31}$$

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

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

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

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

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

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

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

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

Some summarizing remarks are in order.

1. Accelerated expansion is predicted only during periods of over-critical and critical cosmologies parameterized essentially by their duration. The microscopic description would be in terms of phase transitions increasing the size scale of large void. This phase transition is basically a quantum jump increasing gravitational Planck constant and thus the size of the large void. p-Adic length scales are favored sizes of the large voids. A large piece of 4-D cosmological history would be replaced by a new one in this transition so that quite a dramatic event would be in question.

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

3. Cosmological constant can be said to be vanishing in TGD framework and the description of accelerated expansion in terms of a positive cosmological constant is not equivalent with TGD description since Λ means positive energy and negative pressure in GRT framework and negative energy in TGD framework. TGD description has some resemblance to the description in terms of quintessence [53], a hypothetical form of matter for which equation of state is of form $p = -w\rho$, $w < -1/3$, so that one has $\rho + 3p = 1 - w < 0$ and deceleration parameter can be negative. The energy density of quintessence is however positive. TGD does not predict endlessly accelerated acceleration tearing galaxies into pieces if the total purely gravitational energy of large voids is assumed to vanish so that Equivalence Principle holds above this length scale.

2.4.4 TGD counterpart of Λ as a density of dark matter rather than dark energy

The value of Λ is expressed usually as a fraction of vacuum energy density from the critical mass density. Combining the data about acceleration of cosmic expansion with the data about cosmic microwave background gives $\Omega_\Lambda \simeq .74$.

Critical mass density requires also in TGD framework the presence of dark contribution since visible matter contribute only a few percent of the total mass density and $\Omega_\Lambda \simeq .-74$ characterizes this contribution. If one assumes Equivalence Principle above the scale of large voids the total gravitational mass of strings vanishes so that purely gravitational energy has nothing to do with Λ.

Since the acceleration mechanism has nothing to do with dark energy, dark energy can be replaced with dark matter in TGD framework.

The dark matter hierarchy labeled by the values of Planck constant suggests itself. The $1/a^2$ behavior of dark matter density suggests interpretation as dark matter topologically condensed on cosmic strings. Super-canonical bosons and their super partners playing a key role in the model of hadrons and black holes suggest themselves since they have however color interactions and are therefore electromagnetically dark.

If large voids could follow cosmic expansion without expanding themselves, large voids would have constant radius. The density of cosmic strings however reduce gradually so that cosmological constant in TGD sense of word would be reduced. Stationary cosmology predicts that the density of stringy matter and thus dark matter decreases like $1/a^2$ as a function of M^4_+ proper time. This behavior is very natural in cosmic string dominated cosmology and one expects that the TGD counterpart of cosmological constant would behave as $\Lambda \propto 1/a^2$ in average sense. At primordial period cosmological constant would be gigantic but its recent value would be extremely small and naturally of correct order of magnitude if the fraction of positive gravitational energy is few per cent about negative gravitational energy. Hence the basic problem of the standard cosmology would find an elegant solution.

2.4.5 Piecewise constancy of TGD counterpart of Λ and p-adic length scale hypothesis

There are good reasons to believe that TGD counterpart of Λ is piecewise constant. Classical picture suggests that the sizes of large voids increase in discrete jumps. The transitions increasing the size of the void would occur when the galactic strings end up to the boundary of the large void in the repulsive "anti-gravitational" field of the big string in the center of the void.

Also the quantum astrophysics based on the notion of gravitational Planck constant strongly suggests that astrophysical systems are analogous to stationary states of atoms so that the sizes of astrophysical systems remain constant during the cosmological expansion, and can change only in quantum jumps increasing the value of Planck constant and therefore increasing the radius of the large void regarded as dark matter bound state.

Since the set of preferred values of Planck constant is closed under multiplication by powers of 2, p-adic length scales L_p, $p \simeq 2^k$ form a preferred set of sizes scales for the large voids with phase transitions increasing k by even integer. What values of k are realized depends on the time scale of the dynamics driving the galactic strings to the boundaries of expanded large void. Even if all values of k are realized the transitions becomes very rare for large values of a.

p-Adic fractality predicts that the effective cosmological constant Λ scales as $1/L^2(k)$ as a function of the p-adic scale characterizing the space-time sheet implying a series of phase transitions reducing the value of effective cosmological constant Λ. As noticed, the allowed values of k would be of form $k = k_0 + 2n$, where however all integer value need not be realized. By p-adic length scale hypothesis primes are candidates for k. The recent value of the effective cosmological constant can be understood. The gravitational energy density usually assigned 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.

p-Adic prediction is consistent with the recent study [48] according to which cosmological constant has not changed during the last 8 billion years: the conclusion comes from the reshifts of supernovae of type I_a. 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.

Brad Shaefer from Lousiana 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 [49], 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. In principle the phase transitions increasing the size of large voids could be observed as sudden changes of sign for the deceleration parameter.

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

There is an objection against the hypothesis that cosmological constant has been gradually decreasing during the cosmic evolution. Type Ia supernovae at red shift $z \sim .45$ are fainter than expected, and the interpretation is in terms of an accelerated cosmic expansion [55]. If a period of an accelerated expansion has been preceded by a decelerated one, one would naively expect that for older supernovae from the period of decelerating expansion, say at redshifts about $z > 1$, the effect should be opposite. The team led by Adam Riess [56] has identified 16 type Ia supernovae at redshifts $z > 1.25$ and concluded that these supernovae are indeed brighter. The conclusion is that about about 5 billion years ago corresponding to $z \simeq .48$, the expansion of the Universe has suffered a cosmic jerk and transformed from a decelerated to an accelerated expansion.

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

$$\mathcal{F} = \frac{\mathcal{L}}{4\pi d_L^2} \ , \tag{32}$$

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

$$\begin{aligned} d_L &= (1+z)\int_0^z \frac{du}{H(u)} \\ &= (1+z)H_0^{-1}\int_0^z exp\left[-\int_0^u du\,[1+q(u)]\,d(ln(1+u)\right] du \ , \end{aligned} \tag{33}$$

where one has

$$\begin{aligned} H(z) &= \frac{dln(a)}{ds} \ , \\ q &\equiv -\frac{d^2a/ds^2}{aH^2} = \frac{dH^{-1}}{ds} - 1 \ . \end{aligned} \tag{34}$$

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

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

2.5 New anomaly in Cosmic Microwave Background

A new anomaly in CMB has been found. The article by L. Rudnick, S. Brown, L. R. Williams is *Extragalactic Radio Sources and the WMAP Cold Spot* tells that a cold spot in the microwave background has been discovered. The amplitude of the temperature variation is -73 μK at maximum. The authors argue that the variation can be understood if there is a void at redshift $z \leq 1$, which corresponds to $d \leq 1.4 \times 10^{10}$ ly. The void would have radius of 140 Mpc making 5.2×10^8 ly.

In New Scientist [57] there is a story titled about Neil Turoks recent talk at PASCOS entitled Is the Cold Spot in the CMB a Texture?. Turok has proposed that the cold spot results from a topological defect associated with a cosmic string of GUT type theories.

2.5.1 Comparison with sizes and distances of large voids

It is interesting to compare the size and distance of the argued CMB void to those for large voids [54].

The largest known void has size of 163 Mpc making 5.3×10^8 ly which does not differ significantly from the size $8 \times 6.5 \times 10^8$ ly of CMB void. The distance is 201 Mpc making about 6.5×10^8 ly and roughly by a factor 1/22 smaller than CMB void.

Is it only an accident that the size of CMB void is same as that for largest large void? If large voids follow the cosmic expansion in a continuous manner, the size of the CMB void should be roughly 1/22 time smaller. Could it be that large voids might follow cosmic expansion by rather seldomly occurring discrete jumps? TGD inspired quantum astrophysics indeed predicts that expansion occurs in discrete jumps [D8].

2.5.2 TGD based quantum model for astrophysical systems

A brief summary of TGD based quantum model of astrophysical systems is in order.

1. TGD based quantum model for astrophysical systems relies on the evidence that planetary orbits (also those of known exoplanets) correspond to Bohr orbits with a gigantic value of gravitational Planck constant $h_{gr} = GMm/v_0$ characterizing the gravitational interaction between masses M and m. Nottale introduced originally this quantization rule and assigned it to hydrodynamics.

2. TGD inspired hypothesis is that quantization represents genuine quantum physics and is due to the fact that dark matter matter corresponds to a hierarchy whose levels are labelled by the values of Planck constant. Visible matter bound to dark matter would make this quantization visible. Putting it more precisely, the each or the space-time sheets mediating interactions (electro-weak, color, gravitational) between the two physical systems is characterized by its own Planck constant which can have arbitrarily large values. For gravitational interactions the value of this Planck constant is gigantic.

3. The implication is that astrophysical systems are analogous to atoms and molecules and thus correspond to quantum mechanical stationary states have constant size in the local M^4 coordinates (t, r_M, Ω) related to Robertson Walker coordinates via the formulas (a, r, Ω) by $(a^2 = t^2 - r_M^2, r = r_M/a)$. This means that their M^4 radius R_M remains constant whereas the coordinate radius R decreases as $1/a$ rather than being constant as for co-moving matter.

4. Astrophysical quantum systems can however participate in the cosmic expansion by discrete quantum jumps in which Planck constant increases. This means that the parameter v_0 appearing in the gravitational Planck constant $\hbar = GMm/v_0$ is reduced in a discrete manner so that the quantum scale of the system increases.

5. This applies also to gravitational self interactions for which one has $\hbar = GM^2/v_0$. During the final states of star the phase transitions reduce the value of Planck constant and the prediction is that collapse to neutron or super-nova should occur via phase transitions increasing v_0. For black-hole state the value of v_0 is maximal and equals to 1/2.

6. Planetary Bohr orbit model explains the finding by Masreliez that planetary radii seem to decrease when express in terms of the cosmic radial coordinate $r = r_M/a$ [D8]. The prediction

is that planetary systems should experience now and then a phase transition in which the size of the system increases by an integer n. The favored values are ruler-and-compass integers expressible as products of distinct Fermat primes (four of them are known) and power of 2. The most favored changes of v_0 are as powers of 2. This would explain why inner and outer planets correspond to the values of v_0 differing by a factor of 1/5.

2.5.3 The explanation of CMB void

Concerning the explanation of CMB void one can consider two options.

1. p-Adic evolution of cosmological constant as explanation for the constancy of the void size

If the large CMB void is similar to the standard large voids it should have emerged much earlier than these or the durations of constant value of v_0 could be rather long so that also the nearby large voids should have existed for a very long time with same size. Even in the case that all values of k corresponds to possible p-adic length scales characterizing Λ it is possible that no transitions reducing Λ have occurred during the time interval considered.

The constancy of the size of the large void during the time interval considered is predicted by other experimental findings. As alrady found, there is empirical evidence that cosmological constant has remained constant during last 8 billion years at least and the observed jerk suggests that this kind of phase transition has occurred for 13 billion years ago. This would predict that large voids have had the same size between 13 and 8 billion years.

2. Are fractally scaled up variants of large voids possible?

One can also consider the possibility that CMB void is a fractally scaled up variant of large void. The p-adic length scale of the CMB void would be $L_p \equiv L(k)$, $p \simeq 2^k$, $k = 263$ (prime). If it has participated cosmic expansion in the average sense its recent p-adic size scale would be about $16 < 22$ times larger and p-adic scale would be $L(k)$, $k = 271$ (prime). This explanation has no obvious connection with the empirical findings about the behavior of cosmological constant and does not therefore look promising.

3 More detailed view about topological condensation of cosmic strings

The purpose of this section is to represent in more detail the calculations behind the vision discussed in the previous section. As already noticed, free cosmic strings as such cannot correspond to the absolute minima of the action since their action is large and positive.

3.1 Topological condensation of a positive energy cosmic string

It is however useful to build a model of exterior space-time of topologically condensed cosmic string as a solution of Einstein's equations. For a straight string this solution is flat except at the position of the string. What happens is that the 2-dimensional plane orthogonal to the string becomes a conical surface. The angular defect is given by

$$\Delta\phi = \frac{T}{T_{max}} \times 2\pi \ , \ T_{max} = \frac{1}{4G} \ . \tag{35}$$

Here the string tension T refers to the gravitational mass density of the string and this is not necessarily identical with the inertial mass density. Obviously $T_{max} = 1/4G$ represents an upper bound for the gravitational mass density of the string.

The metric can be written as

$$
\begin{aligned}
ds^2 &= dt^2 - dz^2 - \frac{d\rho^2}{k_1^2} - \rho^2 d\phi^2 \ , \\
k_1^2 &= 1 - 4GT \ .
\end{aligned}
\tag{36}
$$

The imbeddings of this metric as an induced metric are easy to find. The simplest imbedding is obtained by considering a map $M^4 \rightarrow S^1$, where S^1 is a geodesic circle of CP_2. Denoting by Φ the angle coordinate of S^1, one has

$$
\begin{aligned}
\Phi &= k\rho \ , \\
1 + R^2 k^2 &= \frac{1}{k_1^2} \ .
\end{aligned}
\tag{37}
$$

The geodesic lines associated with this metric are easy to find in Cartesian coordinates. In M^4 coordinates the geodesics are slightly curved, which is nothing but the lense effect [19]. To see what happens consider geodesic lines in the plane; cut from the plane a sector corresponding to the deficit angle and bend it to form a cone; after this operation project the geodesic lines on the cone to the plane again to see how the geodesics look like in M^4 coordinates. The observation of this bending is possible if the coordinates used by the observers are actually M^4 coordinates rather than space-time coordinates.

The predicted lense effect would serve as a signature for the presence of strings with this kind of exterior metric and the experimental absence of this effect suggests that this metric is not a proper choice for the exterior metric but should be replaced with a metric inspired by Newtonian intuition.

3.2 Exterior metrics of cosmic string as extremal of curvature scalar

Einstein action with induced metric in general gives also solutions for exterior metric which are not gravitational vacua. One might hope these solutions could in the first approximation correspond to Newtonian expectations and give rise only to a small lense effect.

3.2.1 The ansatz

A rather general ansatz applying in case of both positive and negative gravitational string tension and implying radial induced gauge fields in the background space is given by the following expression in cylindrical coordinates for M^4_+

$$
\begin{aligned}
m^0 &= \Lambda t \ , \\
cos(\Theta) &= u(\rho) \ , \\
\Phi &= \omega t + k(\rho) + n\phi \ .
\end{aligned}
\tag{38}
$$

The reason why this ansatz is works is that the components of metric and thus also of curvature tensor depend only on ρ so that field equations reduce to two differential equations. One can get rid of the $g_{t\rho}$ component of the induced metric by assuming $m^0 = \Lambda t + h(\rho)$ as in case of Schwartschild metric.

The interesting components of the induced metric in the cylindrical coordinates are given by the expression

$$
\begin{aligned}
g_{tt} &= \Lambda^2-\omega^2 A \ , \\
g_{\rho\rho} &= -1-A\left[\partial_\rho k)^2+(\partial_\rho u)^2\frac{1}{(1-u^2)^2}\right] \ , \\
g_{\rho t} &= -\omega\partial_\rho kA \ , \\
g_{t\phi} &= -\omega nA \ , \\
g_{\rho\phi} &= -\partial_\rho kA \ , \\
A &= R^2\omega^2(1-u^2) \ , \\
\Lambda^2-\omega^2 A(\infty) &= 1 \ .
\end{aligned} \tag{39}
$$

Note that the induced gauge fields are Abelian. Em and Z^0 fields are proportional to each other and classical color field is proportional to induced Kähler form and vanishes for vacuum extremals. This can be seen as a signature of color confinement.

3.2.2 Field equations as conservation laws

The conservation law for color charge corresponding to $\Phi \rightarrow \Phi+\epsilon$ gives the first differential equation:

$$
\partial_\rho\left[(G^{\rho\rho}\partial_\rho k+\frac{G^{\rho\phi}n}{\rho}+G^{\rho t}\omega)sin^2(\Theta)\sqrt{g}\right] \ = \ 0 \ . \tag{40}
$$

For $m^0+\Lambda t+h(\rho)$ energy conservation one gets rid of the $G^{\rho t}$ term. This equation can be integrated to give

$$
(G^{\rho\rho}\partial_\rho k+\frac{G^{\rho\phi}n}{\rho})sin^2(\Theta)\sqrt{g}=C \ . \tag{41}
$$

and states that the conserved radial flow of $U(1)$ color charge is non-vanishing. This current must flow along the string. Note that for $k=constant$ gives $C=0$.

The second equation can be chosen to correspond to the momentum conservation in say x-direction and would give

$$
\partial_\rho\left[(G^{\rho\rho}+\frac{G^{\phi\rho}}{\rho})\sqrt{g}\right]-G^{\phi\phi}\rho\sqrt{g}=0 \ . \tag{42}
$$

The resulting field equations are extremely non-linear ordinary differential equations for $\Theta(\rho)$ and $\Phi(\rho)=k(\rho)$ having a character of a hydrodynamical conservation law. For $n=0$ one obtains effectively Einstein equations with purely geometric source terms.

$$
\begin{aligned}
G^{\rho\rho} &= \frac{C}{sin^2(\Theta)\partial_\rho k\sqrt{g}} \ , \\
G^{\phi\phi} &= \partial_\rho\left[\frac{C}{sin^2(\Theta)\partial_\rho k}\right]\frac{1}{\rho\sqrt{g}} \ .
\end{aligned} \tag{43}
$$

3.2.3 Linearization

The linearized expression of the Einstein tensor with respect to the deviation $h_{\alpha\beta}$ of the induced metric from flat metric should give a good approximation to the field equations and allow to decide whether the Newtonian picture holds true. The linearized Ricci tensor is given by

$$\begin{aligned} 2R_{\alpha\beta} &= D_\gamma D_\beta h^\gamma{}_\alpha + D_\gamma D_\alpha h^\gamma{}_\beta - D_\alpha D_\beta h - D_\gamma D^\gamma h_{\alpha\beta} \ , \\ R &= D_\alpha D_\beta h^{\alpha\beta} - D_\alpha D^\alpha h \ . \end{aligned} \tag{44}$$

The covariant derivatives are with respect to the flat M^4 metric.

3.2.4 Are field equations consistent with the Newtonian limit?

One can hope that the differential equations are consistent with the Newtonian limit which implies $R_{tt} = g_{tt}R/2$ outside z-axis in the linear approximation. If this is true, the gravitational energy density of the exterior metric would remain vanishing in the linear approximation for the metric so that a minimal modification of the vacuum Einstein equations would be in question. That Newtonian limit makes sense could be due to the fact that Einstein tensor represents the action of a non-linear wave operator on metric. Hence metric should be expressible in terms of its sources and topologically condensed cosmic string defines such a source very naturally.

Newtonian limit corresponds to the approximation

$$g_{tt} - 1 = 2\Phi_{gr} \ , \quad \nabla^2\Phi_{gr} = -4\pi\rho_{gr} \ . \tag{45}$$

For string tension $T = dM/dl$ one has $\Phi_{gr} = 2TGlog(\rho/\rho_0)$ as the 2-dimensional variant of Gauss law shows. This corresponds to the simplified ansatz

$$\begin{aligned} u &= u(\rho) \ , \ \Phi = \omega t + k(\rho) \ , \\ A - A(\infty) &= 2\Phi_{gr} = 4GT \times log(\frac{\rho}{\rho_0}) \ . \end{aligned} \tag{46}$$

This gives

$$\begin{aligned} u^2 &= u^2(\infty) - K \times log(\frac{\rho}{\rho_0}) \ , \\ K &= \frac{16GT}{R^2\omega^2} \ . \end{aligned} \tag{47}$$

The imbedding ceases to exist at certain critical radii corresponding to

$$\begin{aligned} \frac{\rho_{max}}{\rho_0} &= exp(\frac{u^2(\infty)}{K}) \ , \\ \frac{\rho_{min}}{\rho_0} &= exp(\frac{u^2(\infty)-1}{K}) \ , \\ \frac{\rho_{max}}{\rho_{min}} &= exp(\frac{1}{K}) \ , K = \frac{4GT}{R^2\omega^2} \ . \end{aligned} \tag{48}$$

This ansatz with suitably chosen $k_0(\rho)$ could be taken as the lowest order approximation to the solution and one can expand the solution as $X \equiv u^2 = X_0 + \epsilon X_1 + ...$ $k = k_0(\rho) + \epsilon_1 k_1 + ...$ and solve

u_n and k_n by linearizing the field equations around $X = X_0 + ...\epsilon^n X_n$ and $k = k_0 + ...\epsilon^n k_n$ solving (X_{n+1}, k_{n+1}) from the linearized differential equations. One could also proceed by substituting to the right hand side n:th order approximation and linearized Einstein tensor to the left hand side using $n+1$:nt order approximation. Note that the ansatz makes sense also for negative gravitational energy.

3.2.5 Angle defect

The angle defect (or surplus) is given by

$$\Delta\Phi(\rho) = \frac{\sqrt{\rho^2 + R^2u^2n^2}}{\int_0^\rho \sqrt{g_{\rho\rho}}d\rho} \times 2\pi \ . \tag{49}$$

For small values of n the effect is expected to be small. The gravitational angular momentum dJ/dl of the gravitational field per unit length of cosmic string could be non-vanishing and its quantized value determines the value of n:

$$\frac{dJ}{dl} = -\frac{n}{8\pi G}\int G^{t\phi}g_{\phi\phi}\sqrt{g}\rho d\rho d\phi \ . \tag{50}$$

This angular momentum is expected to be small which implies a small angle defect too.

In the case of negative energy cosmic strings the contribution of $g_{\rho\rho}$ to the angular excess is small as compared to the main contribution coming from $\Phi = \omega t + k(r) + n\phi)$ although $g_{\rho\rho}$ becomes infinite at the boundary of the imbeddable cylinder. The same holds true also for positive energy cosmic strings in the lowest order approximation and the angle deficit approaches constant value. Also the contribution from $h(\rho)$ tends to reduce the radial contribution to the effect.

3.3 Exterior metric of negative energy cosmic string with large angle excess

The previous Newtonian ansatz applies also in the case of negative energy cosmic strings and looks rather natural. Also the simple ansatz predicting flat exterior metric generalizes to the case of negative energy cosmic string since angle defect transforms to angle excess. The natural hypothesis is that the induced metric of a vacuum extremal is in question.

If the gravitational mass is negative the simple ansatz for the exterior metric does not work because the metric of circle of CP_2 has wrong signature. One can modify the ansatz by making CP_2 projection 2-dimensional but it is impossible to obtain exactly flat metric. Using spherical coordinates for the homologically trivial geodesic sphere of CP_2 and cylindrical coordinates for M^4, the simplest ansatz producing the angular surplus $\Delta\Phi = (K^2 - 1)2\pi$ in good approximation, is given by

$$\begin{aligned} sin(\Theta) &= \frac{\rho}{\rho_0} \ , \ \Phi = n\phi \ , \\ \rho_0 &= \frac{nR}{\sqrt{K^2-1}} \ , \end{aligned} \tag{51}$$

This imbedding does not correspond to an extremal of a curvature scalar.

The line element for this metric is given by

$$ds^2 = dt^2 - dz^2 - \rho_0^2 \frac{u^2 du^2}{1-u^2} - K^2 \rho_0^2 u^2 d\phi^2 \ ,$$
$$u = \frac{\rho}{\rho_0} \ . \qquad (52)$$

The metric is curved and due to the failure of imbedding above ρ_0 the metric has singularity at ρ_0, which means that the space-time sheet containing straight cosmic string has necessary a finite radius, which brings in mind large voids containing galaxies at their boundaries. One might hope that this metric could serve as the lowest order term in the expansion of an extremal of Einstein action.

3.4 Geodesic motion in the exterior metric of the negative energy cosmic string

Writing the geodesic equations explicitly one finds that the conservation of energy and angular momentum give the conditions

$$\frac{dt}{ds} = E \ ,$$
$$\rho^2 k^2 \frac{d\phi}{ds} = L \ . \qquad (53)$$

In the radial direction one obtains the equation of motion

$$\frac{d^2u}{ds^2} = \frac{u}{1-u^2} \times (\frac{du}{ds})^2 + \frac{L^2}{\rho_0^2} \frac{1-u^2}{u^3} \ . \qquad (54)$$

The cosmic string induces besides ordinary centrifugal acceleration a radial repulsive acceleration

$$g = \frac{u}{1-u^2} \times (\frac{du}{ds})^2 \ . \qquad (55)$$

The geodesic lines lead to the boundary of the cylindrical region. A possible interpretation is that this anti-gravitational force correlates with the small positive value of the cosmological constant assigned to the positive vacuum energy density identifiable as the gravitational energy density defined by Einstein tensor and causing the accelerated cosmic expansion and that this force drives galactic cosmic strings with reduced string tension to the boundary of the large void.

The exterior solution does not represent co-moving matter which conforms with the idea that gravitational space-time sheets correspond to gigantic values of Planck constants implying that even astrophysical objects correspond to stationary quantum states following cosmic expansion only in average sense by quantum jumps leading to a reduction of Planck constant and rapid expansion of the space-time sheet. Classical picture would suggests that these jumps occur when the matter has ended up sufficiently near to the boundary of the large void.

For negative energy cosmic string the angle deficit transforms to an angle surplus and lense effect transforms to its opposite so that light rays coming from a distant object along different sides of cosmic string tend to diverge rather than converge. The experimental absence of the lense effect has been regarded as a strong objection against cosmic strings with positive gravitational mass and can be seen as a support for cosmic strings with negative gravitational mass.

Note that if one completes the space-time sheet by gluing "above" it second cosmic string with positive time orientation and positive gravitational mass the geodesic lines could turn around at the boundary so that the accelerated expansion of the matter would transform to compression.

It is easy to see that simple imbeddings of almost everywhere flat metric do not exist so that the density of gravitational energy in the exterior region is unavoidable. The condition $g_{\rho\rho} = 1$ could be satisfied by assuming $m^0 = t + h(\rho)$ and choosing h properly. This generates however also $g_{t\rho}$ component to the induced metric and to compensate it one should have $\Phi = n\phi + \omega t + k(\rho)$ with k chosen properly. This however generates $g_{t\phi} \neq 0$ which cannot be cancelled and would mean that the solution is rotating.

One obtains also vacuum extremals representing solutions for which gauge charges and angular momentum are non-vanishing by a very simple deformation $\Phi \rightarrow \Phi + \omega t$ of the proposed ansatz. Interestingly, non-vanishing gauge charges are necessarily accompanied by angular momentum and vice versa.

3.5 Matter distribution around cosmic string

The distribution of stars in the vicinity of cosmic string can be modelled using kinetic model for the evolution of the distribution of stars. Assuming that stars have some average mass M and that the situation is non-relativistic the kinetic equation for the distribution of stars reads

$$\frac{dn}{dt} = \nabla \cdot (D\nabla n + \bar{w}n) \ . \tag{56}$$

The second term is the divergence of the current consisting of diffusion term and drift term caused by the Kähler force.

The drift velocity $\bar{w}$ is related to the Kähler force F_K

$$\bar{w} = b\bar{F}_K \ , \tag{57}$$

where b is the mobility of the star. Assuming that one can associate a well defined temperature parameter to the star distribution the mobility is related to the diffusion constant D by the Einstein relation $D = bT$. Kähler force is expressible in terms of Kähler gauge potential

$$\bar{F}_K = \nabla Q\Phi \ . \tag{58}$$

Here $\Phi = kT_sG\omega ln(\rho/\rho_0)$ is the gauge potential of the Kähler electric field. T_s denotes the string tension:

$$T_s \simeq .52 \times 10^{-6} \times \frac{\epsilon}{G} \ .$$

The lower bound for ϵ is about 10^{-7} from the previous considerations. Q is the average Kähler charge of the star: $Q \simeq \epsilon M\sqrt{G}$,

An order of magnitude estimate for diffusion constant is given by $D \simeq \langle v \rangle / n\sigma$, where $\langle v \rangle = \sqrt{(T/M)}$ is the average thermal velocity of star and σ is the collision cross section for collisions with other stars.

The equilibrium distribution corresponds to the cancellation of diffusion and drift currents

$$\frac{dn}{dr} \simeq -\frac{M\sqrt{G}\omega}{T}\partial_r\Phi n \ . \tag{59}$$

In isothermal case one obtains for the distribution of stars the following expression

$$\begin{aligned} n(\rho) &= n_0 exp(-\frac{M\sqrt{G}\Phi_K\omega}{T}) = n_0(\frac{r}{r_0})^{\alpha} \ , \\ \alpha &= \frac{M\sqrt{G}T_sG\omega}{T} \ , \end{aligned} \tag{60}$$

so that a power law behavior results. Unfortunately, concerning the value of the temperature parameter there is nothing interesting to say.

The second alternative is based on the adiabaticity assumption

$$\frac{T}{T_0} = (\frac{n}{n_0})^{1-\gamma} \ , \tag{61}$$

where γ denotes adiabatic constant. In this case one obtains

$$\begin{aligned} n(r) &= n_0(Aln(\frac{r}{r_0}))^{\frac{1}{(1-\gamma)}} \ , \\ A &= (1-\gamma)M\sqrt{G}T_s\frac{G}{T_0} \ . \end{aligned} \tag{62}$$

for the distribution of stars.

3.6 Quantization of the cosmic recession velocity

The statistical analysis of the observational data about red shift of quasars [17] shows that the distribution of emission line red shifts of quasars have a periodicity, which can be explained most nicely by assuming that the recession velocity v calculated from red shift is quantized so that one has, using the standard relation between the recession velocity and distance of the emitting object,

$$v = H_0(r_0 + nR) \ . \tag{63}$$

Here H_0 denotes the present value of Hubble constant. The order of magnitude for the parameter R is $R \simeq 10^8$ ly.

There is also a problem of the association between galaxies and quasars. There are indications that galaxies and quasars form correlated pairs but that the red shift of the quasar is much larger than the red shift of the galaxy [20]. In case that the two systems are actually different physical systems, this implies that the red shift of the quasar member is of non-cosmological origin.

Various explanations for these effects have been proposed. For example, the idea that Universe is multiply connected has been put forward [17]. According to this explanation the emission lines with different red shifts correspond to images of single object: the light emitted from the object can travel several times "around the world" before being detected and the distance to the observe is thus quantized: $r = r_0 + nL$, where L is the size of the non-simply connected Universe. Observations require that L is of the order of $L \simeq 10^8 - 10^9\ ly$.

The TGD based explanation for the phenomenon is similar in spirit to this explanation (see Fig. 3.6.1). The original model for the phenomenon turned out to be inconsistent with the revised view about cosmic strings. The model however allows an obvious modification.

3.6.1 Original model for the quantization of red shifts

The original model was based on the idea is that null geodesic lines around the topologically condensed "big" strings ("big" meant that the parameter $K = \omega^2 R^2$ is not too far from unity) do not leave the 3-space surrounding "big" string in the center of large void of radius of order 10^8 ly and carrying strong Kähler electric field cancelling its magnetic action: for the simplest geodesic the projection to the plane orthogonal to the string is just circle. Galaxies tend to be situated near the boundaries of the 3-space surrounding big string and the light emitted from quasar can travel several times around the string before being detected.

In the recent view "big" means $g > 1$ so that gravitational string tension is negative and huge. "Big" strings in this sense induce repulsive force on photons so that closed orbits are not possible in the recent model. Despite this the earlier model deserves a summary.

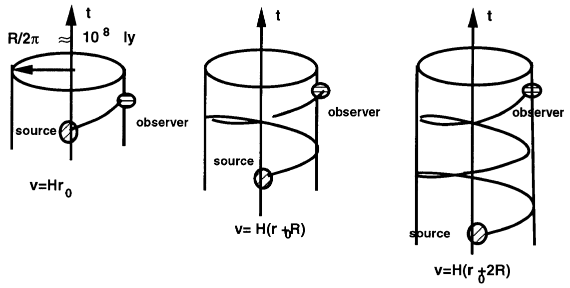

Figure 1: Quantization of the cosmic recession velocity.

A simplified situation is obtained, when the distance R of the emitting quasar and observer from the string is same ($R \simeq 10^8\ ly$) and when the distance along string direction is L. In this case the projection of the light like geodesic on plane is circle and the motion in z-direction is along straight line. The distance travelled by light before its detection is given by the expression

$$r = \sqrt{L^2 + (r_0 + n2\pi R)^2} \ . \qquad (64)$$

If observer and source are in same plane one obtains the previous formula for the quantized recession velocity. The size of the parameter R, which is fixed by the hypothesis that big void regions correspond to cosmic strings is indeed in accordance with the observational constraints.

It is not at all obvious that the orbit of photon can indeed be confined inside the outer critical radius ρ_+ associated with the string having $\omega R \sim 1$: the Kähler charge cannot obviously be all that matters since photons do not couple to it. For "big" strings however $\omega R \sim 1$ holds true. This is indeed the case: the physical reason is the extremely strong gravitational field caused by the big string. To see this consider the equations of motion for an orbit with circular projection in the plane orthogonal to the string. Orbit is characterized by energy conservation condition, momentum conservation condition in the direction of string, masslessness condition and the equation of motion in radial direction (essentially Kepler law)

$$\frac{dt}{ds} = E \ ,$$

$$
\begin{aligned}
\frac{dz}{ds} &= p \ , \\
E^2 g_{tt} - p^2 - \rho^2\omega_0^2 &= 0 \ , \\
\rho\omega_0^2 &= \frac{\partial_\rho g_{tt} E^2}{2} \ ,
\end{aligned} \tag{65}
$$

The last equation forces the photon to a circular orbit if some additional consistency conditions are satisfied and obviously requires Kähler charged string. The expression for the time component of the metric is given by

$$
\begin{aligned}
g_{tt} &= 1 - R^2\omega^2(1-u^2) \ , \\
u &= cos(\Theta) = kln(\frac{\rho}{\rho_0}) \ , \\
k &= \frac{1}{ln(\frac{\rho_+}{\rho_0})} \ .
\end{aligned} \tag{66}
$$

Here $u = cos\Theta$ denotes the coordinate variable of the geodesic sphere S^2 as a function of the radial coordinate approaching value $u = -1$ at the boundary of the cylindrical region surrounding big string. These conditions boil down to the following condition fixing the value for the radius ρ of the circular orbit

$$
cos(\Theta) = \frac{1}{\sqrt{K}}\sqrt{\frac{1-\frac{p^2}{E^2}-K}{1-\frac{Kk^2}{\omega_0^2\rho^2}}} \ . \tag{67}
$$

This equation has real solutions provided the argument of the square root term is positive. In addition the condition $|cos\Theta| \leq 1$ must hold true.

If the longitudinal momentum of the photon vanishes, one has

$$
cos(\Theta) = \frac{1}{\sqrt{K}}\sqrt{\frac{1-K}{1-\frac{Kk^2}{E^2}}} \ . \tag{68}
$$

In the approximation $\frac{Kk^2}{E^2} \simeq 0$ this gives the bounds $1/2 < K < 1$. This condition is not consistent with the assumption that $K = R^2\omega^2$ is a small parameter given by

$$
K = \frac{\epsilon}{2\alpha_K k} \ .
$$

The small value of K is consistent with $p/E \simeq 1$ so that most of photons momentum is in the direction of string. The result means that the original model based on "big" strings in the center of the large void and explaining the observations must be given up.

3.6.2 Modified model for the quantization of red shifts

The modification of the previous model is obvious and much analogous to the topological model for the quantization. If closed galactic strings and torus like space-time sheets containing them and winding around the boundary of the large void are closed and are able to confine photons inside them and thus acting as cosmic wave guides, the photons from a distant star can rotate several times along these space-time sheets and same quantization of the red shift would result also now.

If the proposed explanation for the quantized red shift is correct, one can in principle observe the time development of single object from quasar to galaxy by a series of images, the time difference between two successive images being of the order of 10^8 ly. These images are observed on the same line of sight, when the light comes from a distant object.

4 Cosmic evolution and cosmic strings

In this section a general vision about cosmic evolution based on zero energy ontology is discussed.

4.1 Cosmic strings and generation of structures

p-Adic fractality and simple quantitative observations lead to the hypothesis that 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 near their boundaries long cosmic strings at around which galaxies are organized linear structures like pearls in string. The center of large void contains a cosmic string with negative gravitational energy but positive inertial energy. Galaxies would correspond to similar string like structure with smaller size and linked around the supra-galactic strings. This indeed 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 [17] supports the proposed view. The space-time sheet of large void containing galactic cosmic strings is closed structure. The photons from a distance astrophysical experience radial outwards acceleration and are drifted to the boundaries of the void but they cannot escape this space-time sheet. Hence these photons 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.

4.2 Generation of ordinary matter via TGD counterpart of Hawking radiation?

Positive energy strings can reduce their inertial masses by the analog of Hawking radiation involving the generation of fermion particle-antiparticle pairs, whose negative energy member remains inside string and and positive energy member is radiated away. This mechanism can generate ordinary matter during initial stages of cosmic evolution and its temporal mirror image could give rise to a process analogous to the flow of ordinary matter to a black-hole during the final stages of the cosmic evolution. Highly tangled strings indeed within volume whose radius corresponds to black-hole radius indeed define a very general TGD based microscopic model of a black-hole. 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.

A possible explanation of matter antimatter asymmetry would be in terms of topological condensation of antifermions at cosmic strings and fermions in the region outside cosmic strings. The vanishing of Kähler electric field of string suggests that baryon and lepton numbers of string are same so that the net gauge charges are vanishing. The presence of Kähler magnetic field suggests spin polarization. Exterior region would contain positive energy fermions and negative energy fermions possessing same fermion number so that they would not annihilate to bosons but would make the environment neutral. Since positive energy anti-fermions are effectively absent, the Universe looks matter-antimatter asymmetric.

4.3 How single cosmic string could reduce its Kähler string tension?

The string tension of $g = 1$ cosmic strings is due to Kähler action and has microscopic interpretation in terms of the mass of wormhole contacts having boson interpretation and fermions and super-canonical bosons which correspond to topologically condensed CP_2 type vacuum extremals. The model of hadrons suggests that super-canonical bosons could dominate the mass of $g = 1$ cosmic string. If one accepts the general formula for the string tension in terms of Kähler coupling strength and accepts quantum classical correspondence one must conclude that the total contribution of matter to string tension equals to that of Kähler action.

One can imagine several mechanisms for how cosmic string could reduce its string tension. One mechanism would be the analog of Hawking radiation in which pairs of negative and positive energy elementary particles are created and negative energy particle ends up to the cosmic string and annihilates with ordinary matter. This would lead to a reduction of string tension.

The fact that Kähler action for the infinitely thin cosmic strings depends only on Kähler coupling strength suggests that the cosmic string transforms somehow in the process so that Kähler magnetic field flux remains constant but magnetic energy is reduced. This happens if the cosmic string develops finite transversal size in M^4 degrees of freedom since energy for magnetic flux tubes behaves as $1/S$, S the transversal thickness.

TGD predicts what I have used to call super-canonical bosons and also their super-partners carrying having fermionic quantum numbers of right handed neutrino [D3]. These bosons have no electro-weak interactions and define a particular candidate for dark matter. Super-canonical boson corresponds to single wormhole throat just like fermions and string like hadronic space-time sheets containing super-canonical bosons and their super-partners connected by join along boundaries bonds to partonic space-time sheets have a key role in the recent model of hadrons. Also the model of black-hole as a gigantic hadron like entity relies on them. Two kinds of black-holes, "fermionic" and "bosonic" corresponding to strings and pairs of strings suggest themselves.

4.4 Zero energy ontology, cosmic strings, and consciousness

The combination of zero energy ontology with the cosmic evolution inspires concrete ideas about what the localization of contents of consciousness experience around narrow time interval identified as moment of subjective time could mean.

4.4.1 Zero energy ontology and cosmic evolution

Zero energy ontology means that all matter is creatable from vacuum as zero energy states which can be decomposed to positive and negative energy states whose space-time correlates correspond to partonic 2-surfaces in geometric past and future. This suggests strongly a picture about cosmic evolution beginning with TGD counterpart of Big Bang and ending with that of Big Crunch. It is however more appropriate to speak about "a silent whisper amplified to a big bang" since the amount of gravitational energy of cosmic strings in co-moving volume approaches zero at the limit of initial singularity.

This picture means genuine temporal non-locality and correlations over time interval T characterizing the distance between Bang and Crunch. It is however quite possible that T increases quantum jump by quantum jump and has been very small in past. The gradual shifting of the future end of zero energy state to the geometric future might relate directly to the arrow of subjective time. The usual identification of subjective time with geometric time can be understood if the arrow of subjective time corresponds to the gradual shift of the space-time volume from which the contents of conscious experience are to geometric future. TGD of course predicts a fractal hierarchy of cosmologies within cosmologies. Even elementary particle reactions have interpretation in terms of zero energy states identifiable as kind of mini-cosmologies.

If the main contribution to the contents of consciousness comes from the upper end of the zero energy state, and if T increases quantum jumps by quantum jump, this correlation could be understood and biological life cycle might have interpretation in terms of cosmology in human time scale at some level of dark matter hierarchy. Interestingly, the apparent increase of order suggests that the crunch phase might be experienced as a kind of Ω point. We could live all the subjective time at the Ω point which shifts to the geometric future quantum jump by quantum jump.

In the case of cosmic strings zero energy ontology would mean that cosmic strings are created in pairs of positive and negative energy cosmic strings. The mechanism could be non-local in the sense that the strings need not form tightly correlated pairs. An analogy with TGD based description of particle reaction would allow positive energy fermions from the geometric past and negative energy fermions from geometric future to meet somewhere in between. Bosons would correspond to tightly correlated pairs of positive and negative space-time sheets connected by wormhole contacts.

If the mechanism of generation of strings is local, "bosonic" strings formed by pairs of positive and negative inertial energy cosmic strings connected by connected by wormhole contacts would appear near the bang and crunch so that the density of inertial energy would vanish at this limit. With respect to geometric time single sub-cosmology would correspond to kind of vacuum polarization event for inertial energy. Locality assumption is however not necessary but would be consistent with the fact that Robertson Walker cosmology for which inertial mass density vanishes works so well.

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

1. The first paradox is that the initial state of cosmic evolution seems to correspond to a maximally entropic state. Entropy growth would be naturally due to the emergence of super-canonical matter inside cosmic strings giving them large p-adic entropy which is proportional to mass squared [C5, D3].

2. The dissipative evolution of matter at space-time sheets with positive time orientation would obey second law and evolution of space-time sheets with negative time orientation its geometric time reversal. Second law would hold true in the standard sense as long as one can neglect the interaction with negative energy antimatter and strings. TGD inspired theory of consciousness predicts p-adic evolution and this would mean that negentropic tendency would win. Perhaps matter antimatter asymmetry reflects this.

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

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

4.4.3 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.

5 Cosmic string model for galaxies and other astrophysical objects

The new view about the relationship between gravitational and inertial energy forces to modify the original model based of galaxy based on split cosmic strings. Splitting, although possible, might not be needed since Hawking radiation might replace it as a basic mechanism generating visible matter. By p-adic fractality the mechanism generalizes and provides a universal mechanism for the generation of astrophysical structures and universe can be seen as fractal necklace containing coiled pairs of cosmic strings linked around larger structures of similar kind linked... The mysterious cosmological constant can be identified as the gravitational energy density of cosmic strings and of Kähler magnetic flux tubes.

5.1 Cosmic strings and the organization of galaxies into linear structures

Astronomical observations suggest that galaxies form linear structures
[21]. This inspired the original TGD based model of galaxies as decay products of split cosmic strings forming kind of cosmic fire crackers. The required order of magnitude for the string tension was of order $10^{-6}/G$ the same as the string tension of the cosmic strings predicted by TGD (so that CP_2 radius would reflect itself directly in the galactic dynamics!). The model suggested also a

solution of galactic dark matter problem since the net mass of a ball containing string is expected to depend linearly on the radius of the ball as indeed found.

One problem of this model was that galactic strings ought be in the plane of the galaxy. The galactic jets which one might expect to be parallel to the strings are however orthogonal to the galactic plane which suggests that visible matter condensed on certain points of a long string roughly orthogonal to the galactic plane.

The new view about the relationship between inertial and gravitational energy and the necessity of cosmological constant forces to modify this scenario.

1. The observation that galaxies are organized in linear structures can be understood if the basic structures are $g = 1$ cosmic strings with string tension determined by Kähler actiona nd winding in a spaghetti like manner along the boundaries of large voids. Part of ordinary matter would results as a Hawking radiation from these strings but the very fact these strings are mostly invisible suggests that the matter emitted by them remains in the vicinity of strings. Visible jets orthogonal to the galactic plane usually interpreted in terms of black hole emissions could correspond to the emission of Hawking radiation from these structures. Galaxies are concentrations of visible matter around these strings and they are roughly orthogonal to the plane of galaxy.

2. The generation of positive and negative energy matter with zero net energy from vacuum does not contribute to the inertial energy but increases gravitational mass. This has occurred already during string dominated critical period during which the density of gravitational mass behaves as $\rho \propto 1/a^2$ as a function of the light cone proper time and the mass per co-moving volume is proportional to a. The fractality of TGD inspired cosmology suggests that the creation pairs of positive and negative energy cosmic strings giving rise to cosmologies inside cosmologies has occurred also later in smaller length scales. In particular, galaxies and even smaller structures could be seen as cosmologies within cosmologies. Pairs of cosmic strings and magnetic flux tubes are not visible and are thus excellent candidates for the dark matter.

   If the initial inertial and gravitational mass per unit length of these objects is same as that for a free string, the order of magnitude for the gravitational energy density of dark matter per volume is predicted correctly if the length L of string inside sphere R is proportional to its radius: $L \propto R$. Hence the original model would not be totally wrong. Galaxies could be strongly knotted relatively short cosmic strings linked around the long cosmic strings like pearls in a necklace. Their shortness would mean that they do not contribute significantly to the mass of the void.

3. p-Adic fractality suggests that even smaller astrophysical structures might involve strings linked with larger strings linked with...., the cosmic necklace would be a fractal necklace. In the case of Sun a string of length $L \sim 10^{11}$ m, which is not far from the distance $AU = 1.5 \times 10^{11}$ m between Earth and Sun, would be needed whereas the radius of Sun is $\sim 7 \times 10^8$ meters. Thus the magnetic flux tubes resulting form these strings could wind around solar system and bind the entire system into single coherent magnetic structure. For Earth one would have $L \sim 3 \times 10^5$ m, which is smaller than the radius $R = 6.4 \times 10^6$ m of Earth. What makes this interesting is that quite recently it has been announced that Earth contains a previously unidentified core region with size of 3×10^5 m [22]. This picture suggest a universal mechanism for the evolution of the solar system replacing the existing Newtonian model based on the amplification of gravitational perturbations.

5.2 Cosmic strings and dark matter problem

Consider now the idea that the presence of cosmic strings might solve the dark matter puzzle [23]. The presence of the dark matter is indicated by the velocity spectrum of the distant stars (at distance of few tens of kilo-parsecs from the center of the galaxy), which according to the recent observations [27, 28] approaches to a constant depending on the galaxy in question and having the general order of magnitude $V \simeq 10^{-3}$.

One can estimate the velocity V of a distant star in galactic plane from Kepler law (the spherically symmetric model for galaxy suggests that this argument indeed applies)

$$\frac{V^2}{R} = \frac{GM(R)}{R^2} \ , \tag{69}$$

where $M(R)$ denotes the mass inside a sphere of radius R. Since the mass of the cosmic string dominates the mass inside a sphere of radius R one gets the following very rough estimate for the effective gravitational mass inside the sphere of radius R

$$M(R) \simeq n2TR \ , \tag{70}$$

where $n > 1$ accounts for the fact that straight string is not in question. From the known velocity V one obtains for the string tension the estimate

$$T \sim \frac{V^2}{4nG} \sim \frac{10^{-6}}{4nG} \sim v_D T_{free} \ . \tag{71}$$

This estimate is of the same order of magnitude as the lower bound of string tension obtained from the Jeans criterion. The result is also consistent with the assumption that, due to their gravitational binding to strings, stars rotate with the same velocity as strings.

Recall that an upper bound for the string tension of the TGD cosmic string is given by

$$T = \frac{1}{8\alpha_K R^2} \simeq .52 \times 10^{-6}\frac{1}{G} \ .$$

This is roughly twice the required tension for $n = 1$ so that TGD is consistent with the experimental input. The effective string tension of the co-moving string also increases for $r \rightarrow r_0$ (see the general description of cosmic string solution) and diverges at $r = 0$. Furthermore, since the cosmic string is not straight there appears additional factor n making $M(R)$ larger than the simple estimate above.

On basis of these observations one has a strong temptation to think that the still existing cosmic strings, possibly thickened to magnetic flux tubes, correspond to galactic and extragalactic dark matter. At this stage one must leave open whether the naive argument leads to a correct form for the velocity spectrum of stars. Whether or not true this prediction would have nice features in that it would relate the velocity spectrum directly to the size and age of the galaxy since the velocity v determines the recent size of the visible galaxy (if it corresponds to the recent distance of the string end from the center of galaxy): the older the galaxy with given size the smaller the rotational velocity v. Elliptic galaxies are older than spiral galaxies: rotational velocities for the elliptic galaxies are indeed smaller than for spiral galaxies [28]. Furthermore, the rotational velocities increase with the size of the galaxy, when the age of the galaxy is kept constant: also this feature is in qualitative accordance with observed facts [27, 28].

An interesting question is whether one could explain the angular momentum of galaxies in terms of the tidal forces acting between the galaxies [29] at the opposite ends of a string (having length of order 10^5 light years. The idea is following. For free cosmic string there is a flux of angular momentum of order Tar^2 (using Robertson-Walker coordinates (a, r))) through the end of the string, which produces a correct order of magnitude for the galactic angular momentum at time a given by $J \sim Ta^2r^2 = Tr_M^2$, $r_M \sim 10^5\ ly$.

5.3 Estimate for the velocity parameters

The first task is to fix the value of the velocity parameter, to be denoted by V, appearing in the general solution describing one arm of the split cosmic string. In the region, where linearized equations of motion hold the orbital velocity V of the cosmic string is constant.

The radius of the singular region associated with cosmic string increases with some velocity v_D identifiable as the velocity with which the size of a typical galaxy (defined for example as the distance of spiral arm L from the center of galaxy) is about $L \simeq 10^4 - 10^5$ light years [24, 26]. The condition $vT < L$, where $T \simeq 10^9 - 10^{10}$ years is the typical age of the galaxy, gives the estimate

$$v_D \quad < \quad 10^{-5} \ , \tag{72}$$

for the velocity v_D using the velocity of light as unit.

One can relate the velocity v_D to the string tension if one accepts the assumption that the relative motion of the string ends results from the shortening of strings, which in turn results from the decay of the string ends to elementary particles (some of them possibly exotics). A rough estimate for the velocity of the shortening of the string [19] is based on the observation that the velocity

$$v \quad \simeq \quad TG \sim 10^{-6} \tag{73}$$

seems to set the time scale for the various dynamical processes leading to the decay of strings [19]: for example, the shortening of loop with radius L via gravitational radiation as well as the shortening of the string connecting the monopole pair takes place with this velocity [19]. This velocity is considerably smaller than the typical velocity $V \simeq 10^{-3}$ [27, 28] of the distant stars moving in the galactic plane, which in turn can be understood using Kepler law.

The idea that the spiral arms of the spiral galaxy correspond to cosmic strings seems to be in accordance with the observational facts. In case of Milky Way [26] the distance of spiral arms is about $L = 10^4 - 10^5$ light years from the center of the galaxy so that the order of magnitude for the velocity v_D is $v_D \sim 10^{-6} - 10^{-5}$. Furthermore, spiral arms are known to recede from the center of the Milky Way [26].

The model suggests also an explanation for the observed bar like structure connecting the ends of the spiral arms of the spiral galaxies. The gravitational field is most intense near the string end so that the density of the ordinary matter is expected to be largest near the end of the string. On the other hand, the orbit of the string end is straight line so that "bar" like structure might be formed [24], when the ends of the spiral arms recede from each other.

It should be stressed that the visible form of galaxies is not so closely related with the form of strings contrary to the original expectations (we used the term "spiral string"). This is clear from the observation that the total change of angle ϕ is smaller than $\pi/2$, which means that strings are really not "spiral" like. Of course, this result holds for free strings and it might be that condensation in fact creates spiral structure somehow. A more conventional explanation is the generation of density waves with spiral structure [18] and the presence of strings might have something to do with this phenomenon.

5.4 Galaxies as split cosmic strings?

It is not clear whether the Hawking radiation from a coiled pair of cosmic strings is able to explain galactic visible matter. The reason is that the cosmic strings responsible for linear structures formed by galaxies are not visible along their entire length. One might argue that same applies also the knotted and linked galactic cosmic string pairs. If this is the case, the dark matter problem becomes visible matter problem. A possible solution of the problem is based on split cosmic strings with splitting possibly resulting in the collision of galactic strings with the long supra-galactic strings.

This scenario has indeed some attractive features (see Fig. 5.4).

1. The ends of the split cosmic string create strong gravitational fields and serve as seeds for the galaxy formation. Lense effect [19] is predicted to be a signature of the string pairs. The fact that spiral galaxies have in general two arms, has a nice topological explanation.

2. One ends up to a rather simple scenario for the evolution of the galaxy.
   i) The splitting occurs most probably during the string dominated phase for $t < L \sim 10^4\sqrt{G}$ (L is essentially CP_2 radius) and results most naturally from the collision of two strings.
   ii) The split strings begin to decay by emitting particles from their ends. The decay leads to a shortening of the split strings with constant velocity v so that the ends of the split strings recede from each other. This velocity can be identified with the velocity parameter $v \sim TG$ associated with the motion of the spiral arms. A correct size for the visible part of the galaxy is predicted.
   iii) Decaying cosmic string ends provide a model for the 'central engines' associated with the galactic nuclei [25]. The energy production by string decay turns out to be of same order of magnitude as the energy production in quasars assuming that the energy is produced in a narrow jet parallel to the string (momentum conservation favors this option). This was proposed as an explanation for the visible jets associated with the active galaxies as resulting from the interaction of the decay products with the ordinary matter. The fact that these jets are orthogonal to the galactic plane suggests Hawking radiation from supra-galactic string stimulated by the collision as an alternative explanation.
   iv) Co-moving cosmic strings happen to rotate with the same velocity as distant stars (relative to the center of galaxy) are found to rotate. The gravitational binding of stars by the average gravitational field created by cosmic strings would explain the rotational velocity spectrum.

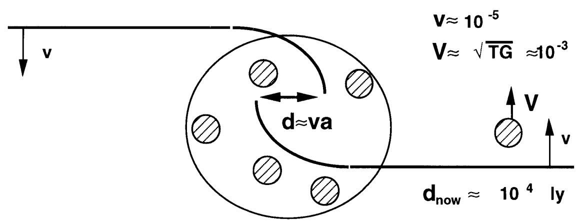

Figure 2: String model for galaxies.

In the following the model will be discussed in more detail to see whether it really works. The value for the velocity parameter v will be derived, Jeans criterion for the formation of the structures around a split cosmic string will be discussed, a simple toy model for a galaxy using spherically symmetric mass distribution will be constructed and the possibility that cosmic strings might provide a solution to the galactic dark matter problem will be studied.

5.4.1 Jeans criterion for the galaxy formation

It is not obvious that Jeans criterion for the generation of structures by gravitational interaction can be applied to galaxy formation in the recent situation differing so dramatically from Newtonian framework. One can however check what Jeans criterion would give in the case of split cosmic strings [19].

1. The size L of the density fluctuation leading to the formation of a structure satisfies the inequality

$$l_J \quad < \quad L < l_H \ , \tag{74}$$

where the Jeans length l_J is given by [19]

$$l_J \quad \simeq \quad 10 v_s t \ , \tag{75}$$

where v_s denotes the velocity of sound. Notice that the formation of structures is not possible at the radiation dominated era since Jeans length is larger than horizon: $l_H \simeq t < l_J \simeq 10t$ since the velocity of sound is of order 1.

2. When radiation and matter decouple from each other (corresponding to the value of about $a_{dec} = 10^8$ light years [30]), the formation of galaxies becomes possible due to the lowering of the pressure, which leads also to the lowering of the sound velocity v_s from $v_s \simeq 1$ to $v_s \simeq 10^{-5}$ (thermal velocity of hydrogen). Jeans length shortens by a factor 10^{-5} and the formation of structures becomes possible.

In accordance with the idea that the split strings act as seeds for the galaxy formation, one can identify Jeans length as the minimal distance between the ends of the split string, which leads to a formation of galaxy

$$v_D a_{dec} \quad > \quad l_J \ . \tag{76}$$

Using the values for a_{dec} and l_J one obtains lower bounds for the velocity v_D between the ends of the galactic string and for the string tension of the galactic strings (accepting the proposed relationship between v_D and string tension)

$$\begin{aligned} v_D &> 10^{-6} \ , \\ T &> \frac{10^{-6}}{G} \ . \end{aligned} \tag{77}$$

One obtains also a lower bound for the recent size L_{now} of the galactic nuclei assuming that the decay of galactic strings continues with velocity v_D

$$L_{now} \quad > \quad 10^4 \ ly \ . \tag{78}$$

These numbers are in accordance with the estimate obtained for the string tension of a typical galactic strings and with what is known about recent sizes of the galaxies [24].

5.4.2 Spherically symmetric model

The imbeddability requirement plays central role in TGD inspired cosmology and the galaxy model based on spherically symmetric mass ($M(r) = kr$) distribution is of some interest. This model could be regarded as a large length scale idealization of galaxy mass distribution. In case that galactic dark matter consists of the exotic decay products of the cosmic string the model might be even reasonably realistic. The line element for an energy momentum tensor characterized by energy density $\rho(r)$ and pressure $p(r)$ is given by the expression $ds^2 = A(r)dt^2 - B(r)dr^2 - r^2 d\Omega^2$ and to find an imbedding for this metric one can use the general imbedding ansatz introduced, when discussing the imbedding of Reissner- Nordström metric.

Under rather general assumptions about the mass density the time component of the metric for a spherically symmetric mass distribution $M(r)$ (the mass inside the sphere of radius r) is given by the expression $g_{tt} = 1 - 2GM(r)/r$. In present case one would obtain $g_{tt} = constant$ so that some of the underlying assumptions must fail. The following form leads to a correct gravitational force

$$g_{tt} = 1 + 2Gkln(\frac{r}{r_0}) \ . \tag{79}$$

The gravitational force in the Newtonian limit is $2Gk/r = 2GM(r)/r^2$ and implies that Kepler law to be used later to derive velocity distribution of distant stars is indeed applicable.

The general expression for the metric component g_{tt} in terms of the imbedding ($m^0 = \lambda t, \Theta = \Theta(r), \Phi = \omega t + f(r)$)

$$g_{tt} = \lambda^2 - R^2\omega^2 sin^2(\Theta) \ , \tag{80}$$

which gives

$$sin^2(\Theta) = \lambda^2 - 1 - \frac{2Gk}{R^2\omega^2} ln(\frac{r}{r_0}) \ . \tag{81}$$

Imbedding fails for two critical radii r_{in} ($sin^2|(\Theta) = 1$) and r_{out} ($sin^2(\Theta) = 0$)

$$\begin{aligned} ln(\frac{r_{in}}{r_0}) &= \frac{(\lambda^2 - 1 - R^2\omega^2)}{2Gk} \ , \\ ln(\frac{r_{out}}{r_0}) &= \frac{(\lambda^2 - 1)}{2Gk} \ . \end{aligned} \tag{82}$$

An interesting question is whether one could relate the inner critical radii to the existence of the galactic nucleus having diameter of the order of 2 parsecs (.65 light years).

5.5 Cylindrically symmetric model for the galactic dark matter

TGD allows also a model of the dark matter based on cylindrical symmetry. In this case the dark matter would correspond to the mass of a cosmic string orthogonal to the galactic plane and traversing through the galactic nucleus. The string tension would the one predicted by TGD. In the directions orthogonal to the plane of galaxy the motion would be free motion so that the orbits would be helical, and this should make it possible to test the model. In this kind of situation general theory of relativity would predict only an angle deficit giving rise to a lens effect. TGD predicts a Newtonian $1/\rho$ potential in a good approximation.

Spiral galaxies are accompanied by jets orthogonal to the galactic plane and a good guess is that they are associated with the cosmic strings. The two models need not exclude each other. The vision about astrophysical structures as pearls of a fractal necklace would suggest that the visible matter has resulted in the decay of cosmic strings originally linked around the cosmic string going through the galactic plane and creating $M(R) \propto R$ for the density of the visible matter in the galactic bulge. The finding that galaxies are organized along linear structures [21] fits nicely with this picture.

6 Cosmic strings and energy production in quasars

One of the basic mysteries of astrophysics are so called 'central engines' in the centers of the galaxies [25]. These engines are very massive, have very small size of at most few light hours, their luminosity fluctuates in hour time scale, their electromagnetic spectrum is non-thermal and they are often accompanied by two jets in opposite directions. One should also understand why some galaxies are active (have a pair of jets) and others are not. A mysterious property of jets is their microstructure: main jets with length of order 10^6 light years are accompanied by short jets with length of order one light year and with directions parallel to the long jets.

In the standard model the central engine is a galactic black hole but the mechanism of the jet production is not well understood. In the following it is shown that decaying cosmic string ends provide a good candidate for the central engine. Note that in the standard picture jets are orthogonal to galactic plane whereas in the proposed model jets are parallel to the galactic plane. One could consider also the possibility that galaxies are formed in the splitting of cosmic strings orthogonal to galactic plane but this option will not be discussed here.

6.1 Basic properties of the decaying cosmic strings

The rate for the shortening of a split galactic cosmic string can be deduced by an order of magnitude argument

$$\begin{aligned} v &\sim kTG \ , \\ T &\simeq \frac{2\times 10^{-7}}{G} \ . \end{aligned} \qquad (83)$$

T is the string tension of the cosmic string. k is some numerical constant not too far from unity. The numerical study of the *ordinary* cosmic strings [19] gives support for this order of magnitude estimate.

Taking the age of the Universe to be $a \sim 10^{11}$ years and assuming that the cosmic string is split in early phase of cosmology, the length of the portion of the decayed string is of the order

$$L \sim kTGa \simeq 2\times 10^4 k \ \text{light years} \ , \qquad (84)$$

which is of the same order of magnitude as the typical size of the visible part of the galaxy.

An estimate for the rate of the energy production by single cosmic string is given by

$$P \sim Tv = kT^2G \sim \frac{4\times 10^{-14}k}{G} \sim 10^{47}k \times m(proton)/sec \ . \qquad (85)$$

The energy production in quasars is roughly 10^{14} times larger than the energy production in Sun, which is about 10^{25} W: this gives $P \sim 10^{49} m_p/sec$. In order to have same order of magnitude one should have

$$k \sim 25 \ . \tag{86}$$

The required value of k looks suspiciously large and suggests that the energy flux from the decaying cosmic string could well be a jet directed to a narrow cone, which would increase the observed effective energy flux.

6.2 Decaying cosmic string ends as a central engine

It seems that the decaying cosmic string could explain elegantly the basic properties of the central engines. There are two alternative scenarios to be considered.

I) Galaxies are formed around the ends created in the splitting of a very long cosmic string.

II) Galaxies are formed by a decay of a piece of cosmic string. The decay of a finite piece of cosmic might explain the existence of some stellar objects accompanied by jet like structures.

In both cases the rate of the string decay gives a correct upper bound for the recent size of the visible part of the galaxies. Consider now the explanation of basic characteristics of active galaxies.

1. Visible jets are created by the energy beams

   The rate of the energy production in the decay of a cosmic string is few per cent about the estimated energy production in quasars assuming spherical symmetry. A correct rate for the observed energy flux from quasars is obtained if the energy from the decay of the string is liberated in a jet. Since two string ends are involved, the visible two-jet structure is an automatic consequence. The jets emerging from the active galactic nuclei are created by the interaction of the primary jets with the ordinary matter.

2. Quasars.

   Quasars differ from the ordinary galaxies only in that the energy jet from the cosmic string decay meets Earth. This explains the non-thermal nature of the spectrum and the absence of the atomic lines for the most intensive quasars (they are masked by the primary radiation). The rapid variations (a time scale of an hour) in the luminosity can be understood as resulting from the motion of the cosmic string inducing changes in the direction of the jet. Also the similarity between active and inactive galaxies is an automatic consequence.

3. Active-inactive distinction.

   For the option I possible explanation is that the galactic black hole has absorbed all matter around the galaxy and the jets coming from the decay of the cosmic strings have nothing with which to interact. It could however happen that the two jets interact with matter in very distant regions creating two tightly correlated jets but apparently originating from very distant sources. It could also occur that string ends are inside a galactic black hole for inactive galaxies so that the decay products remain inside the black hole and no visible jets are created. For the option II inactive galaxies without any jets, one can also consider the possibility that the piece of cosmic string has already decayed completely.

4. Dark matter halo.

   There are two alternative explanations for the velocity spectrum of the distant stars around the galaxy. The first, purely TGD based, explanation is that distant stars are gravitationally bound to the rotating cosmic string. Cosmic string indeed rotates with a correct velocity and, being Kähler charged, creates a genuine gravitational field unlike neutral cosmic string.

The standard explanation is based on the assumption that galaxy is surrounded by a dark matter halo.

An interesting possibility is that a halo of dark matter could result from the decay of the cosmic strings, perhaps in the form of ordinary and exotic neutrino like matter predicted by TGD. The decay could produce also part of the visible matter around the galactic nucleus. The jet model suggests that most of the decay products of the cosmic string escape the visible region of the galaxy but massive and Kähler charged particles with a proper sign of charge could remain bound to the cosmic string. Dark variants of ordinary elementary particles, in particular dark neutrinos, suffer classical Z^0 force below appropriate p-adic length scale. Clearly, Kähler force favors the generation of matter antimatter asymmetry. The average density in the halo would however be perhaps too small to explain the velocity spectrum.

5. Production mechanism for ultrahigh energy cosmic rays.

   The decay of the cosmic string should also give rise to ultrahigh energy cosmic rays. This production mechanism would provide an alternative for the production mechanisms based on the acceleration of the charged particles [it is difficult to conceive how any acceleration mechanism could lead to the generation of ultra high energy cosmic rays].

6.3 How to understand the micro-jet structure?

The long jets with length of roughly 10^6 light years have microstructure consisting of micro-jets with length of order one light year. This feature could be regarded as a shortcoming of the model. A possible TGD based explanation is based on lense effect on the gravitational field of the split cosmic string (scenario I).

In option I, a lense effect, caused by the strong gravitational field of the cosmic string itself, and creating multiple images could be involved. Since charged cosmic string is in question, the situation is more complicated than for the ordinary cosmic string. For instance, photon could rotate several times around the cosmic string before leaving the galactic region. The disappearance of the effect in distant regions (of length of order light year) could be understood if the energy jet were on the wrong side of the string at large distances or the distance between the jet and cosmic string would become so large that photons would not anymore circulate around the string.

6.4 Gamma-ray bursts and cosmic strings

Gamma ray bursters [31] are now quite generally believed to have a cosmological origin. The energy flux from the gamma ray bursters (assuming spherical symmetry and cosmological origin and distance of order 10^8 ly) is about 10^{16} times the energy flux from Sun and by a factor of 10^2 larger than the total energy flux from the decaying cosmic string. The order of magnitude is same as for the energy flux of quasars. Typically the energy is produced in pulses lasting for a few seconds but also long lasting bursts consisting of a train of smaller pulses with a duration of order second are detected. It seems that the system emitting pulses is in some sense near criticality. The distribution of the gamma ray bursters is isotropic.

An interesting possibility is that decaying cosmic strings might explain also this phenomenon. The string would produce a continuous stream of energy, which fails slightly to meet Earth. Small perturbations causing the string end to oscillate (random oscillation of the direction of a flicker is a good analogy) imply that the beam of energy can meet the Earth at each period of oscillation and cause a sequence of pulses. A unique maximum intensity is predicted.

The shape of the pulse is predicted to reflect only the time development of the direction of the cosmic string rather than the actual intensity distribution of the pulse and this should make it possible to distinguish between TGD based and other explanations for the bursts. For instance, the typical bi-modality of the pulse could reflect directly to a perturbation taking string direction from the equilibrium position and bringing it back. The asymmetry of this perturbation caused by dissipative effects should explain the asymmetry of the two intensity peaks. The observed hardness-brightness correlation could be understood as following from the cosmic red shift and cosmic time dilatation increasing the observed duration of the pulse.

From the estimate that there are

$$\frac{dN}{dt} \sim 10^{-6}\ year^{-1}\ galaxy^{-1}$$

bursts per galaxy per year and taking the average duration t_P of the pulse to be

$$t_P \sim 1\ sec\ ,$$

one obtains a *very* rough estimate for the probability that a given galaxy acts as a gamma ray burster at a given moment as

$$P \sim t_P \times \frac{dN}{dt} \sim 10^{-13}.$$

One can estimate the solid angle Ω of the cone to which the energy of the decaying cosmic string is emitted: the probability P for galaxy being a burster, is simply the product of the probability $p(A)$ that galaxy is active multiplied with the probability $\Omega/(4\pi)$ that Earth happens to be in the solid angle Omega

$$P = \frac{p(A)\Omega}{4\pi} \sim 10^{-13}\ ,$$

which gives

$$\Omega \sim \frac{4\pi P}{p(A)} \sim \frac{10^{-12}}{p(A)}\ .$$

To proceed further an estimate for the probability of being active galaxy is needed. The value of Ω had better to be rather small since the oscillations in the direction of the cosmic string leading to fluctuations in the intensity of beam must be of the order of Ω and too large fluctuations are not expected (cosmic string is quite a heavy object!).

7 The light particles associated with dark matter and the correlation between gamma ray bursts and supernovae

Both the model for dark matter identified as cosmic strings or their decay products and the model for gamma ray bursts identified as beams resulting in the fire cracker like decay of cosmic strings were constructed more than decade ago. During year 2003 came several astonishing observations, which at first seemed to be in a dramatic conflict with both the model of the dark matter and the model of gamma ray bursts.

It however turned out that these findings allow to relate, modify, and generalize as many as five models sketched at that time as the first applications of TGD. The subjects modelled were following:
i) The final state of a rotating star predicting flux tube like magnetic field along the symmetry axis [D4],
ii) Dark matter identified as cosmic strings or their decay products,
iii) Sunspots identified as the throats of magnetic flux tubes feeding magnetic flux to larger space-time sheet and behaving effectively as magnetic monopoles [D7]),

iv) Gamma ray bursts explained as cosmic firecrackers resulting from the decay of split cosmic strings to elementary particles,
v) The anomalous e^+e^- pairs produced in the collisions of heavy nuclei at energy near the Coulomb wall as decay products of lepto-pions consisting of color excited leptons [F7].

7.1 Correlations between gamma ray bursts and supernovae

The established correlation between gamma ray bursts and supernovae is certainly the cosmological discovery of the year 2003 [32, 33].

1. The first indications for supernova gamma ray burst connection came 1998 when a supernova was seen few days after the gamma ray burst in the same region of sky. In this case the intensity of the burst was however by four orders of magnitude weaker than for the typical gamma ray bursts so that the idea about the correlation was not taken seriously. On 29 March, observers recorded a burst christened as GRB030329. On 6 April, theorists at the Technion Institute of Technology in Israel and CERN in Geneva predicted that there would be signs of a supernova in the visible light and infrared spectra on 8 April [32]. On cue, two days later, observers picked up the telltale spectrum of a type Ic supernova in the same region of sky, triggered as the collapsing star lost hydrogen from its surface. It has now become clear that a large class of gamma ray bursts correlate with supernovae of type Ib and Ic [34], and that they could thus be powered by the mere core collapse leading to supernova. Recall that supernovae of type II involve hydrogen lines unlike those of type I. Supernovae of type Ib shows Helium lines, and Ic shows neither hydrogen nor helium but intermediate mass elements instead. Supernovae of type Ib and Ic are thought to result as core collapse of massive stars.

2. One of the most enigmatic findings were the "mystery spots" accompanying supernova SN1987A at a distance of few light weeks at the symmetry axis at opposite sides of the supernova [35] Their luminosity was nearly 5 per cent of the maximal one. SN1987A was also accompanied by an expanding axi-symmetric remnant surrounded by three concentric rings.

3. The latest finding [36] is that the radiation associated with the gamma ray bursts is maximally polarized. The polarization degree is the incredible 80 ± 20 per cent, which tells that it must be generated in an extremely strong magnetic field rather than in a simple explosion. The magnetic field must have a strong component parallel to the eye sight direction.

7.1.1 Do topologically condensed cosmic strings become co-moving magnetic flux tubes serving as seeds for the formation of stars and galaxies

According to the model for the formation of stars and galaxies proposed already fifteen years ago, topologically condensed pieces of cosmic strings perhaps resulting in the collision of long possibly knotted cosmic strings would serve as seeds making possible formation of lumps of matter forming later stars. The assumption that the pieces of cosmic strings result in the collision of cosmic strings leading to the splitting of them to pieces with some fractal length distribution perhaps concentrated around p-adic length scales would explain why the mass $M(R)$ of galactic dark matter inside a sphere of radius R is proportional to the radius: $M(R) \propto R$.

1. Topologically condensed cosmic strings as co-stretching magnetic flux tubes

I considered already 15 years ago a model for topological condensation of cosmic strings assuming that strong radial Kähler electric fields are generated to compensate the large positive magnetic action. Cosmic strings are actually a special case of magnetic flux tube solutions of field equations.

This leads to a revised vision for what happens for topologically condensed cosmic strings. This model does not exclude the presence of the radial electric fields due to the charging of the cosmic strings.

Cosmic strings, which are in the ideal situation string like objects of type $X^2 \times Y^2$, X^2 string like object in M^4_+ and Y^2 geodesic sphere of CP_2 or a piece of it, generate an M^4_+ projection which increases in thickness so that the solution becomes increasingly thicker magnetic flux tube. In the topological condensation the open ends of the string disappear and thus no decay to elementary particles can occur. Thus the topological condensation would stabilize the cosmic strings against decay.

1. The simplest assumption is that the topologically condensed piece of a magnetic flux tube of finite length co-stretches with the expanding universe so that its length increases as $L \propto a$, a light cone proper time.

2. The requirement that magnetic flux is conserved and quantized implies $B \propto 1/S$, S the transverse area of the flux tube. The condition that magnetic energy is conserved, implies $S \propto L \propto a$ and $B \propto 1/a$. This of course applies both to the magnetic and Z^0 magnetic flux tubes.

The assumption that topologically condensed pieces of cosmic strings remain co-stretching forever is questionable, and it might be that when the thickness of the flux tube reaches a critical value corresponding to a Compton length of say pion or lepto-pion, expansion stops, and the flux tube freezes to a very long hadronic or lepto-hadronic (color) magnetic flux tube (a Kähler field giving rise to em or Z^0 field gives also rise to a classical color field).

"Wormhole magnetic fields" consist of pairs of magnetic flux tubes represented by space-time sheets with opposite time orientations and thus having opposite energies. These structures have zero energy and I have proposed that they play a key role in the physics of living matter. In particular, they could be generated by intentional action by first generating a p-adic variant of the wormhole magnetic field representing the intention to generate wormhole magnetic field, and then transforming it to its real counterpart in quantum jump. One cannot exclude the possibility that cosmic strings could also be generated as zero energy pairs of cosmic strings with opposite time orientation. This would make possible to intentionally create universe from nothing. This is actually the only possibility if one poses the boundary condition that no quantum numbers flow out of the future light cone at its boundary.

2. Stars and galaxies as gravitational condensates around fragments of cosmic strings

The gravitational condensation of matter around short parallel flux tubes topologically condensed at larger space-time sheets is a natural mechanism for generating structures like galaxies and stars. The pieces of magnetic flux tubes would form expanding ferro-magnet like structure in the self-consistent magnetic field defined by the by the return flux flowing at the space-time sheet at which strings have suffered topological condensation. The contribution of the magnetic flux tubes to the total mass of the star can be small and the ordinary matter can be seen as decay products of cosmic strings as in the earlier model. Similar mechanism with different initial length of topologically condensed cosmic strings and resulting in fragmentation in the collision of say two long cosmic strings could give rise to the birth of galactic nuclei.

According to the TGD based model of primordial critical cosmology, the transition from string dominated to radiation dominated cosmology should have occurred at $a_0 \sim 10^{-10}$ s, and one could argue that the topological condensation of the magnetic flux tubes should have started at this time. With this assumption the recent thickness of the magnetic flux tubes would be $d = (a/a_0)^{1/2} \times 10^4 \sqrt{G} \sim 10^{-16}$ m for $a \sim 10^{11}$ years. This corresponds to a hadronic length scale. Quite generally, this would suggest that at light cone proper time a the fragments of long cosmic strings, which have survived the decay to elementary particles, have typical length $L \sim a$.

From the recent length of about light month associated with super nova SN1987A (identifying the mysterious light spots as ends of the flux tube), one can deduce that the length L_0 of the cosmic strings at a_0 would have been $L_0 \simeq 10^{-14}$ m, roughly the Compton length of pion. The corresponding magnetic field would be about 10^{16} Tesla and extremely strong. Fields of similar magnitude have been proposed to result in the core collapse of supernovae [38]. It however seems that the flux tubes of the primordial magnetic fields cannot explain the highly polarized synchrotron radiation but that the temporary extremely strong Z^0 magnetic field induced by the core collapse are responsible for the polarization.

Magnetic and Z^0 magnetic flux tubes as templates for the formation of material structures is an idea borrowed from TGD inspired theory of consciousness and of bio-systems as macroscopic quantum systems [10]. The TGD based quantum model for bio-matter assumes that the magnetic flux tubes of Earth serve as templates for the formation of bio-matter, and also define what I have called magnetic bodies controlling pre-biotic and biotic evolution [L4]. Also the idea that magnetic flux tubes act as wave guides and make precisely targeted communications possible originates from TGD inspired theory of consciousness [K1]. Thus magnetic flux tube structures could serve as templates for and even guide the evolution of matter in all length and time scales: this is certainly in spirit with the fractality of TGD Universe.

7.1.2 A mechanism producing gamma ray burst and polarized synchrotron radiation

The dynamo model for the final state of a rotating star leads to a model for gamma ray bursts consistent with ultrahigh polarization of the synchrotron radiation. The model is consistent with the standard model for the radiation beams from neutron stars.

1. Generalizing the dynamo model for the final state of rotating star

TGD based dynamo model for the final state of rotating star predicts that the rotation axis star contains extremely strong magnetic or Z^0 magnetic field. The field along the axis can also be helical and B_ϕ would naturally result from the rotation of the matter. While attempting to interpret the dynamo model I proposed that the axial field might somehow relate to a cosmic string. This might be indeed the case.

What I did not realize 15 years ago that many-sheeted space-time allows both magnetic and Z^0 magnetic dynamo fields and their symmetry axes of the fields need not coincide.

1. The atomic nuclei of even ordinary condensed matter can carry anomalous weak charges due to the presence of color bonds between nucleons having at their ends exotic quarks with mass of order electron mass and carrying also weak charges [F8, F9]. If some color bonds become charged they have also net weak charges. The Z^0 repulsion due to the weak bosons with Compton length of order atomic radius can explain the low compressibility of condensed matter and give rise to the repulsive term in van der Waals equation. Weak repulsion due to exotic weak bosons is expected to become important in the extremely dense phase of matter inside star.

2. There are good justifications for the assumption that Z^0 magnetic axis is parallel to the rotation axes- Z^0 magnetic field having neutron number as its source receives a large varying contribution dictated by the flow dynamics of the star. Hence Z^0 magnetic field is expected to be very strong, at least in the situations in which currents of different dark matter particle species do not cancel each other. In particular, the ejection of dark neutrinos during the formation of supernova is expected to generate a strong Z^0 charge due to the anomalous Z^0 charges of nuclei. This induces both Z^0 electric field and Z^0 magnetic fields. Since rotation and Z^0 magnetic fields are so strongly coupled, the Z^0 magnetic and rotation axes should coincide.

3. The fact that the rotation axis of the star is rather stable is consistent with the primordial origin of the Z^0 magnetic field and suggests that Z^0 magnetic field as the primordial cause of the rotation.

4. Magnetic axis need not coincide with the rotation axis. The direction of the magnetic field of the star can be reversed (this is happening just now in case of Sun). This suggests that magnetic field does not have primordial origin and reflects the dynamics of the star.

5. TGD based variant for charged particle currents frozen to the magnetic field lines (assumed to have infinity conductivity in magnetohydrodynamics) are non-dissipative supra currents flowing along magnetic flux tubes of the magnetic and Z^0 magnetic fields. These currents in turn generate magnetic and/or Z^0 magnetic fields with field lines circulating around the rotation axes and thus make the magnetic field along symmetry axis helical.

6. Both in the case of magnetic or Z^0 magnetic field, the charged particles topologically condensed at the super-conducting flux tubes could be also spin polarized and amplify the field further.

In many-sheeted space-time topologically condensed magnetic flux tubes must feed their fluxes to larger space-time sheets so that a many-sheeted variant of the dipole field would result. The return fluxes would flow at larger space-time sheet and correspond to thicker flux tubes with weaker intensity of the magnetic flux. The regions, where the flux would be transferred between space-time sheets could correspond to join along boundaries bonds or wormhole contacts. In the latter case they would look like magnetic charges. As the in case of the sunspots, a fractal structure containing flux tubes inside flux tubes is expected [D7].

The mysterious light spots associated with SN1987A [35] could correspond to join along boundaries bonds or the throats of the magnetic flux tubes of or primordial Z^0 magnetic flux tubes.

3. Synchrotron radiation in strong Z^0 magnetic field as a mechanism generating strong polarization

Usually the degree of polarization for the radiation from supernovae is around few per cent [40]. The polarization associated with gamma ray burst GRB021206 is however incredibly high 80 ± 20 per cent and maximal polarization of the radiation [36]. This requires extremely strong Z^0 magnetic field. The helical Z^0 magnetic field along the rotation axis can have flux quanta of astrophysical size and is ideal for accelerating dark charges flowing along the rotation axis and for producing dark photon synchrotron radiation leaking out in the direction of the rotating magnetic axis and transforming to ordinary photons by a mechanism analogous to decoherence of laser beams [F9, J6]. Gamma ray bursts could be seen as a particular case of this radiation resulting when an especially strong dark current (say dark electron current) flows along the rotational axis in an exceptionally strong dynamically generated Z^0 magnetic field, and induces a beam of synchrotron radiation along the rotating magnetic axis.

The radiation is linearly polarized with the polarization direction and intensity defined by the vector

$$\overline{n} \times (\overline{n} \times \overline{B}^Z) = \overline{B}^Z - B_z^Z cos(\theta)\overline{n} \ ,$$

where $\overline{n}$ is the direction of the observer in the direction of the axial magnetic flux tubes and characterized by the angle θ. The direction of polarization is constant during the observation period if the symmetry axis associated with B^Z coincides with the rotation axis. It is essential that magnetic and Z^0 magnetic fields are not parallel and reside at different space-time sheets. The intensity is proportional to the square of the polarization factor given by

$$(B^Z)^2 \times \left(1 - cos^2(\alpha)cos^2(\theta)\right) \ , \quad cos(\alpha) \equiv \frac{B_z^Z}{B^Z} \ .$$

If the Z^0 magnetic field has only z-component, the intensity is proportional to $(B^Z)^2 sin^2(\theta)$ and at minimum.

4. Radial compression as a mechanism producing strong Z^0 magnetic field

A sudden compression in radial directions orthogonal to the rotation axis at the core collapse could be seen as a process analogous to the squeezing of the tooth paste tube. A strong non-dissipative supra current along the axis of magnetic field is induced because this is the route of the lowest resistance. This current in turn generates a strong magnetic field component B^Z_ϕ, and the charges accelerated in the axial direction in this field emit synchrotron radiation with a direction of polarization tangential to the magnetic field component B^Z_ϕ. If all nuclei possess anomalous Z^0 charges, the matter flow along rotation axis can generate very strong Z^0 magnetic field so that there are good hopes of explaining the anomalously high value of polarization of the synchrotron radiation.

The three expanding ring like structures associated with SN1987A [41] could be identified as being due to dark Z^0 currents rotating around the strong axial Z^0 magnetic field. Even the identification as torus like flux quanta of Z^0 magnetic field induced by the very strong Z^0 current along the z-axis is possible. This kind of Z^0 magnetic dark currents rotating around axial Z^0 magnetic field could be even responsible for the rings associated with planets like Saturnus and even with the ring current associated with Earth. This picture conforms with the model for the formation of solar system in which macroscopically quantum coherent dark matter serves as a template around which ordinary matter is condensed [D7, J6] as also with the explanation of tritium beta decay anomaly assuming that Earth's orbit is surrounded by dark neutrino belt [F8].

It is known that spherical and even axial symmetry is broken in case of SN1987A and this is consistent with the fact that magnetic and Z^0 magnetic axis are not parallel. Let L be the line of sight orthogonal to the plane S of sky, and R the projection of the ring to S. Let z-axis correspond to L and x- and y-axis to the directions of the minor and major axis of R. Denote by E_z and E_y the projections of ejecta to S and xz-plane. From the figure 2 of [37] one can deduce that the plane of the ring forms an angle of 44 degrees with respect L. The symmetry axes of E_y resp. E_z forms an angle of 45 degrees resp. 15 degrees with respect to x-axis. From this one can conclude the polar and azimuthal angles of the symmetry axis of ejecta are $\theta = 45.4$ degrees and $\phi = 9$ degrees. A good guess is that this axis corresponds to the rotation axis and axis of Z^0 magnetic field tilted by 45.4 degrees with respect to the line of sight parallel to the magnetic axis. Mystery spots are known to be located at this axis too [37] so that they could indeed correspond to sunspot like throats at which Z^0 magnetic flux is transferred between space-time sheets.

7.1.3 Magnetic flux tubes as wave guides

Magnetic flux tubes are ideal wave guides forcing the confined radiation to propagate in a precisely targeted manner along them. Topological light rays (MEs) accompany magnetic flux tubes involved and have interpretation as space-time correlates for a radiation propagating in the waveguide defined by the magnetic flux tube. They are accompanied by coherent light generated by light like vacuum currents associated with then. Topological light rays would couple to Alfwen waves representing transversal oscillations of the magnetic flux tubes propagating also with light velocity.

The wave guide function of magnetic flux tubes suggests a generalization and modification of the model of gamma ray bursts. Gamma ray bursts would be generated by the synchrotron radiation generated in the acceleration of charges when they move along rotation axis with dynamically generated component B^Z_ϕ. Part of the resulting radiation would end up to a rotating magnetic flux tube bundle in the direction of the rotating magnetic axis. The initial channelling at the magnetic flux tubes would force synchrotron radiation to propagate to distant parts of the universe in a precisely targeted manner. This mechanism would explain the observed universal properties for the gamma ray bursts [42] difficult to understand in the models involving mergers, say collisions of white dwarf binaries [34]. As already noticed, the model is consistent with the existing model for the ordinary radiation arriving from supernovae and thought of as involving a beam rotating with the supernova.

7.1.4 Gamma ray bursts as dark photons

In [D7] a model for dark graviton with a large value of Planck constant is developed. This yields also a model for the de-coherence of dark graviton and for what happens in the detection of dark gravitational radiation. The model applies also to dark gauge bosons.

1. The basic new element is that dark bosons are associated with topological light rays which are N-sheeted multiple coverings of M^4. The energy absorbed in the detection of a dark boson would be N-fold whereas the frequency for detections is expected to be $1/N$ times lower so that in average sense dark bosons would behave like normal ones. The events in which dark gravitons with large N are detected would be interpreted as noise. Same could apply to other dark bosons. Dark matter would be only apparently dark.

2. The propagation of of dark boson can be regarded as a sequential de-coherence in which pieces with smaller value of Planck constant and thus smaller energy are split off from the original dark boson. Frequency is not altered in this process.

   Gamma ray bursts could correspond to dark photons with very large value of N so that strongly targeted and very intense beam of ordinary photons results in the de-coherence process.

7.1.5 Gamma ray bursts as collective transitions of cosmic strings identified as scale up hadrons

According to the TGD based model [F4], hadrons consists of two kinds of matter. Valence quark space-time sheets have fused to single structure by color bonds, the "Pomeron" of the physics before QCD. This structure is in turn connected by bonds (possibly carrying the color of sea quarks) to string like hadronic space-time sheet characterized by Mersenne prime M_{107} and containing super-canonical bosons giving the dominating contribution to the mass of light baryons.

The black-hole like characteristics of the hadronic space-time sheet, which conform with the experimental findings at RHIC, plus the general vision about the formation of neutron stars and quark stars via the fusion of hadronic space-time sheets encourage a generalization to a model for the microscopic structure of black-holes as highly tangled strings inside black-hole horizon. Black-hole would be kind of scaled up hadron.

The Mersenne primes characterizing the hadronic space-time sheet in the hierarchy extending from cosmic strings to hadrons would belong to the set $\{M_n|vertn = 2, 3, 5, 7, 13, 17, 19, 31, 61, 89, 107\}$. The quarks contained by cosmic string would be labelled by rather small p-adic primes. Cosmic strings would give rise to primordial black-holes decaying to ordinary matter and magnetic flux tubes with a lower string tension. Gamma ray bursts could result in collective quantum transitions of cosmic strings involving several steps with end products of final state at each step characterized by a smaller Mersenne prime. For gamma ray bursts produced by super-novae the value of Mersenne prime would be probably $k = 107$.

Note that ordinary hadrons need not define the lowest level of the hierarchy since also M_{127} copy of hadron physics appears in the TGD based model of nucleus. If Gaussian Mersennes are allowed then much more levels are possible: in particular, in length scale range especially relevant for living systems.

7.1.6 Gamma ray bursts and quantum phase transitions in the scale of string like object

The model of hadrons behind hadronic mass calculations leads to the vision that super-canonical bosons are responsible for the most of hadronic mass [F4, F5]. This in turn leads to a microscopic model for neutron stars, quark stars, and black-holes as highly entangled hadronic strings resulting in the fusion of hadronic strings. Also cosmic strings would contain super-canonical matter and separate from environment by black hole horizon.

All these objects would be macroscopic quantum systems and their quantum transitions could generate dark gamma rays, dark gravitons, and other dark particles decaying to ordinary particles in de-coherence phase transition.

A model for dark graviton emission assignable to the gravitational quantum transition of astrophysical objects characterized by gigantic gravitational Planck constant is discussed in [D4]. Dark gravitons would correspond to pulses of ordinary gravitons resulting in de-coherence rather than continuous flow of gravitons. These pulses might be dismissed as noise in measurement philosophy based on standard quantum mechanics.

7.2 Lepto-pions as a signature dark matter?

The identification of cosmic strings as the ultimate source of both visible and dark matter does not exclude the possibility that a considerable portion of topologically condensed cosmic strings have decayed to some light particles. In particular, this could be the situation in the galactic nuclei. On the other hand, if some fraction of cosmic strings evolve to magnetic flux tubes, these flux tubes identifiable as dominant part of the dark matter can carry phases of some exotic particles serving as signatures of the dark matter. Quite recent experimental findings [43] suggest that these exotic particles could be lepto-hadrons predicted by TGD [F7].

7.2.1 Two anomalies

The idea that lepto-hadrons might have something to do with the dark matter has popped up now and then during the last decade but for some reason I have not taken it seriously. Situation changed towards the end of the year 2003. There exist now detailed maps of the dark matter in the center of galaxy and it has been found that the density of dark matter correlates strongly with the intensity of monochromatic photons with energy equal to the rest mass of electron [43].

The only explanation for the radiation is that some yet unidentified particle of mass very nearly equal to $2m_e$ decays to an electron positron pair or directly to gamma pair. Electron and positron are almost at rest and this implies a high rate for the annihilation to a pair of gamma rays. A natural identification for the particle in question would be as a lepto-pion. By their low mass lepto-pions, just like ordinary pions, would be produced in high abundance, in lepto-hadronic strong reactions and therefore the intensity of the monochromatic photons resulting in their decays would serve as a measure for the density of the lepto-hadronic matter. Also the presence of lepto-pionic condensates can be considered. Lepto-pions decay directly to both gamma pairs and electron-positron pairs. Indeed, galaxy is for long time known to be a source of positrons and there is no generally accepted mechanism producing them [43].

The second anomaly was the microwave interstellar medium emission observed by WMAP used to map the anistropy of cosmic microwave spectrum [39]. Unfortunately, the anomaly reached my attention for more than 4 years later. Anomalous lines at frequencies $f = 23; 33, 41, 61, 94$ GHz have been observed. In good approximation they correspond to harmonics of single frequency of f= 10 GHz. For the cyclotron transitions of electron the required magnetic field would be about 0.36 Tesla. The identification would be in terms of cyclotron transitions of dark electrons or of their Cooper pairs residing at magnetic flux tubes of galactic magnetic fields and characterized by so large value of Planck constant that cyclotron energy is above thermal energy. The emitted cyclotron radiation would decay into bunches of ordinary photons with same frequency but much smaller energy.

7.2.2 Lepto-hadron as explanation of gamma ray anomaly?

In the chapter [F7] I have discussed the TGD based explanation for the anomalous production of electron positron pairs in the collisions of heavy nuclei at energies corresponding to the height of Coulomb wall. The effect was observed for more than fifteen years ago [58] but after string model revolution has been forgotten by theorists like many other anomalies of particle physics. The hypothesis is that so called lepto-pions are produced in the strong, non-orthogonal, and rapidly varying electric and magnetic fields of the colliding nuclei. Lepto-hadrons are color bound states of colored excitations of leptons predicted by TGD defining an asymptotically non-free QCD. Actually an entire hierarchy of non-asymptotically free QCD:s are allowed in TGD Universe.

These findings force to take seriously either the identification
a) of the dark matter as lepto-hadrons or
b) of lepto-pions as a signature of dark matter, which itself would be basically magnetic energy associated the with cosmic strings transformed to magnetic flux tubes in topological condensation. Of course, leptopions could correspond to only a small fraction of dark matter and one can quite well imagined that they are created in strong interactions of leptobaryons.

In fact, lepto-pions are not the only possibility. The TGD based model for tetra-neutrons [59] [F8] is based on the hypothesis that mesons made of scaled down versions of quarks corresponding to Mersenne prime M_{127} (ordinary quarks correspond to $k = 107$) and having masses around one MeV could correspond to the color electric flux tubes binding the neutrons to form a tetra-neutron. The same force would be also relevant for the understanding of alpha particles.

7.2.3 Why lepto-hadrons cannot directly correspond to dark matter?

The identification of lepto-hadrons as dark matter raises several questions leading to the conclusion that lepto-pions are most probably only a signature of dark matter.

1. Why the ratio of the lepto-hadronic mass density to the mass density of the ordinary hadrons would be so high, of order 7? Could an entire hierarchy of asymptotically non-free QCDs be responsible for the dark matter so that lepto-hadrons would explain only a small portion of the dark matter? Is even the hierarchy of QCD:s enough?

2. Under what conditions one can regard lepto-hadronic matter as a dark matter? Could short life-times of lepto-hadrons make them effectively dark matter in the sense that there would be no stable enough atom like structures consisting of say charged lepto-baryons bound electromagnetically to the ordinary nuclei or electrons? But what would be the mechanism producing lepto-hadrons in this case (nuclear collisions produce lepto-pions only under very special conditions)?

3. What would be the role of the many-sheeted space-time: could lepto-hadrons and atomic nuclei reside at different space-time sheets so that lepto-baryons could be long-lived? Could dark matter quite generally correspond to the matter at different space-time sheets and thus serve as a direct signature of the many-sheeted space-time topology? Magnetic flux tubes are excellent candidates for the space-time sheets accommodate the dark matter but there are good reasons to believe that magnetic energy is considerably higher than the energy of particles condensed on magnetic flux tubes so that magnetic energy is the best candidate for dark matter.

These objections suggest that lepto-pions serve only as a signature of dark matter. The recent vision about dark matter suggests that all particles can appear as dark variants and reside at magnetic flux tubes and leptopions could be only particular kind of dark matter. Of course, dark matter itself could correspond also to the magnetic energy of the magnetic flux tubes and cosmic strings.

7.2.4 Lepto-pions topologically condensed on magnetic flux tubes as a signature of dark matter?

Lepto-pions and other leptohadrons producing copiously lepto-pions could reside at magnetic of Z^0 magnetic flux tubes of thickness of order Compton length of lepto-pion. These strings could be seen as kind of very long lepto-hadronic strings. Also long hadronic flux tubes carrying coherent states of ordinary pions are possible and Z^0 flux tubes beaming the gamma ray bursts could correspond to them.

One could identify the lepto-hadronic magnetic flux tubes as structures generated later in the cosmic evolution, when the magnetic flux of hadronic flux tubes flow to larger space-time sheets. The transversal length scales of the flux tubes would be in ratio m_e/m_p and the magnetic field would be by a factor of about 10^{-6} weaker, about 10^{10} Tesla whereas the magnetic field of supernovae are around 10^9 Tesla. If the thickness of the magnetic flux tube at the moment of the annihilation of lepto-pion is of the order of Compton length of electron, one obtains an estimate for its thickness at the moment when the transition to the radiation dominated phase occurred.

If the strength of the magnetic field is of order $eB \sim m_e^2 \sim 10^9$ Tesla, the cyclotron frequency would be of same order as electron mass $eB/m_e \sim m_e$ and in gamma ray region. For $eB \sim m_p^2$ the field strength would be 10^{15} Tesla and cyclotron energy would be of order proton mass. Harmonics of this line might serve as a signature for the strength of the magnetic field. The monochromatic gamma lines at electron mass could also result in cyclotron transitions of electrons if the magnetic field at magnetic flux tubes that $eB = m_e^2$ holds true in high precision.

One can imagine two mechanisms of lepto-pion production.

1. The magnetic and Z^0 magnetic fields associated with the magnetic flux tubes give rise to classical color fields, which suggest that one could regard the flux tubes as macroscopic color magnetic and possibly also color electric flux tubes carrying lepto-hadrons, which produce copiously lepto-pions in their reactions.

2. In heavy ion collisions lepto-pion production is caused by the presence of the rapidly varying non-orthogonal electric and magnetic fields of colliding nuclei, whose "instanton density" $E \cdot B$ is non-vanishing (this means that the magnetic flux tube has higher than 2-dimensional CP_2 projection). The amplitude for lepto-pion production as a decay of the coherent state is proportional to the Fourier component of the "instanton density". The mechanism could be at work also now if magnetic flux tubes carry strong charges and generate radial electric fields. Lepto-pions would serve as signature for rapid changes of the magnetic and electric fields induced by rapid deformations of the magnetic flux tubes.

7.2.5 Solar X-ray halo and scaled up QCDs at magnetic flux tubes

Quite recently New Scientist told about an explanation proposed by Kostantin Zioukas and his colleagues [45] for the X-ray halo of Sun in terms of axions, one of the many candidates for the dark matter [44]. The X-ray halo of Sun was detected at 1940. The halo extends from the surface of Sun (free path for photons increases at the surface). The X-ray intensity decays exponentially and extends several solar radii from the surface. The energy range of X-rays is $3 - 15$ keV. The origin of the X-ray halo has remained a mystery.

The axions in the required mass range are predicted by certain higher-dimensional theories [45]. The axions would be produced in the solar core and because of their extremely long lifetime they would propagate to the surface of Sun and some fraction of non-relativistic axions would remain bound in the solar gravitational field where they would decay. The estimated mean distance of the proposed axion population from the solar surface is about 6.2 solar radii. Zioukas and his colleagues are able to deduce the value of the coupling constant $g_{A\gamma\gamma}$ characterizing the rate of axion decay and the interaction cross section of axion with matter from the fact that the X-ray luminosity must be proportional to $g^4_{A\gamma\gamma}$. The resulting lifetime of the axion is about 10^{21} s to be compared with the lifetime of ordinary pion about 10^{-16} s.

TGD suggests an alternative explanation based on a non-asymptotically free exotic QCD at a magnetic flux tube corresponding to a p-adic length scale $L(k)$ for which the scaled down value of pion mass corresponds to mass of about 3 keV. Assuming that pion corresponds to $k = 107$ ($k = 109$ is the second candidate) this gives $2^{(k-107)/2} \sim m_{\pi(107)}/m_{\pi(k)}$. The lower limit for the energy spectrum would favor the p-adic length scale $L(139)$ giving $m_{\pi(139)} \simeq 2.2$ keV. The lifetime of lepto-pion would be scaled up by a factor 2^{16} so that one would have $\tau \sim 10^{-11}$ s. One cannot exclude the presence of several scaled up QCDs with $k = 139, 137$ and $k = 131$ being the most favored ones in the energy range of about 3 octaves spanned by the X-ray spectrum.

In the recent case the intensity of the X-ray halo from a given spherical volume V of the halo defining the pixel is determined by the density $dn(\pi)/dl$ of the exotic pions per unit length of the magnetic flux tube and the length $l(V)$ of the magnetic flux tube inside the volume, which is expected behave as $l(V) \sim V^{1/3}$. A rough estimate is

$$I(V) \sim \frac{dn(\pi)}{dl} \times l(V) \times \Gamma \times \langle E(\pi)\rangle \Delta\Omega \ ,$$

where $\Delta\Omega = A/4\pi R^2$ is the solid angle defined spanned by the active detection area A of the measuring instrument at a given point of the magnetic flux tube and R is the distance of Earth from Sun. In principle this allows to estimate the density of exotic pions per unit length of the magnetic flux tube.

The exponential decay of the intensity with distance from the surface of the Sun would suggest that magnetic flux tubes might be regarded as threads extending from the solar surface and returning back to it, and that the probability of a path of given length decreases exponentially with its length. If the probability for the appearance of a thread of given length is proportional to the Boltzman weight $exp(-E_B/T)$, where E_B is magnetic energy of the thread and T is temperature parameter, this indeed holds true.

The intensity of the magnetic field at the flux tubes can be estimated from the nominal value $B_E = .5 \times 10^{-4}$ Tesla of the Earth's magnetic field at the space-time sheet $k = 169$. By scaling one would obtain $B = 2^{169-139} B_E = 5 \times 10^4$ Tesla. The field is extremely strong and could be perhaps assigned to remnants of primordial cosmic strings. Note that also Z^0 magnetic field could be in question in which case dark matter coupling to scaled down copies of electro-weak bosons would be in question [F6, F9].

7.2.6 Do the length scale ratios for astrophysical objects reflect Compton length ratios of elementary particles?

The ratio for the size $L_l \sim 10^5$ light years of a galactic nucleus to the distance $L_h \sim 1$ light month between the light spots of super nova gives an estimate for the ratio of the lengths of the lepto-hadronic and hadronic magnetic flux tubes. This would predict $L_l/L_h \sim 10^6$ and that the ratio of transverse thicknesses $d_l/d_h = 10^3$, which is the ratio of lepto-pion Compton length scale scale to proton Compton length. This would suggests that the length scale hierarchy for astrophysical objects could represent a scaled up version of the p-adic length scale hierarchy associated with elementary particles.

7.2.7 Frequency cutoff for zero point frequencies as a test for many-sheeted space-time?

For a quantum system mode lable in terms of harmonic oscillators (say photon field) the frequency spectrum in the thermal equilibrium obeys Planck distribution. Besides this the system exhibits zero point fluctuations whose energy density is given by $\rho_0(f) = 8\pi^2 f^3$ ($\hbar = c = 1$) in the 3-dimensional case. Zero point fluctuations appear in many models of physical phenomena such as X-ray scattering in solids, Lamb shift, Casimir effect, and the interpretation of the Aharonov Bohm effect (for references see [46]).

The zero point fluctuations are predicted to appear also in electronic systems, and the experimentally measured spectral density of the current noise measured by Koch [47] in Josephson junctions provides a direct support for this prediction. The fluctuations have been observed up to the frequency of $f = .6$ THz which corresponds to a microwave wavelength of .5 mm.

It has been proposed by Beck and Mackey [46] that if these fluctuations are associated with the vacuum energy, the total vacuum energy density associated with these fluctuations cannot exceed the recently measured dark energy density of the Universe: this leads to a cutoff frequency of $f_c = (1.69 \pm .05)$ THz for the measured frequency spectrum.

In TGD framework dark matter is ordinary matter at larger space-time sheets. First of all, the finite size of the space-time sheet poses an IR cutoff. p-Adic length scale hierarchy suggests that that there is also UV cutoff that corresponds to the next p-adic length scale in the hierarchy. Hence the frequencies above the UV cutoff would correspond to oscillations at smaller space-time sheets. The interpretation would be in terms of de-coherence.

Thus a given space-time sheet would contain half octave of frequencies between the frequency cutoffs $f_{low}(k) = c/L(k) \propto 2^{-k/2}$ and $f_{up}(k) = c/L(k+1)$. Cutoff frequencies would come as half octaves for k integer as predicted by the most general form of the p-adic length scale hypothesis. The stronger form of the hypothesis favors prime values of k. Note that for $k = 179$ (prime) the predicted cutoff frequency would be $f_c(179) \simeq 1.74$ THz, which happens consistent with the prediction of [46] deduced from the estimate for the dark matter density. This need not be an accident. According to the TGD based model explaining the finding that neutrino mass depends on the environment, neutrinos can condense on several space-time sheets and neutrinos in dense matter travel along $k = 179$ space-time sheet [F3].

The problem is that the spectral density would be same at every space-time sheet. One might however hope that the shift of the spectrum from a space-time sheet to another one manifests itself as some kind of structure at half-integer octaves of a basic frequency. By using a suitable arrangement one might be even able to eliminate some space-time sheet so that a gap would result. An interesting question is how the measurement instrument could be constructed to detect only the frequencies associated with a space-time sheet corresponding to a fixed value of k.

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