More about TGD and Cosmology

Matti Pitkänen

orcid:0000-0002-8051-4364.
email: matpitka6@gmail.com,
url: http://tgdtheory.com/public_html/,
address: Valtatie 8, as. 2, 03600, Karkkila, Finland.

Abstract

This chapter can be regarded as second part of the previous chapter and is develoted to various applications and problems of cosmology. Much of the text is written decade or two ago.

1. The anomalies of CMB are discussed as a natural continuation of discussion of the counterpart of inflationary cosmology in TGD framework.
2. Simulating Big Bang in laboratory is the title of the next section. The motivation comes from the observation that critical cosmology could serve as a universal model for phase transitions.
3. Some problems of existing cosmology are considered in TGD framework. Discussion includes certain problems of the cosmology such as the questions why some stars seem to be older than the Universe, the claimed time dependence of the fine structure constant, the generation of matter antimatter asymmetry, the problem of the fermion families, and the redshift anomaly of quasars. A mechanism for accelerated expansion of Universe is also considered. In the recent framework this reduces to the critical cosmology and cosmological constant can be assigned to the effective space-time defining GRT limit of TGD.
4. There is a section about matter-antimatter asymmetry, baryogenesis, leptogenesis and TGD discussing whether right-handed neutrino suggested to generate SUSY in TGD framework could be the key entity in fermiogenesis.
5. The remaining sections are devoted to Hogan's theory about quantum fluctuations as new kind of noise and the question whether hyperbolic 3-manifolds emerging naturally in Zero Energy Ontology might be useful in TGD inspired cosmology and explain some redshift anomalies.

1 Introduction

This chapter can be regarded as second part of the previous chapter [K31] and is develoted to various applications and problems of cosmology. Much of the text is written decade or two ago.

1. The anomalies of CMB are discussed as a natural continuation of discussion of the counterpart of inflationary cosmology in TGD framework.

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

Some problems of existing cosmology are considered in TGD framework. Discussion includes certain problems of the cosmology such as the questions why some stars seem to be older than the Universe, the claimed time dependence of the fine structure constant, the generation of matter antimatter asymmetry, the problem of the fermion families, and the redshift anomaly of quasars. A mechanism for accelerated expansion of Universe is also considered. In the recent framework this reduces to the critical cosmology and cosmological constant can be assigned to the effective space-time defining GRT limit of TGD.

There is a section about matter-antimatter asymmetry, baryogenesis, leptogenesis and TGD discussing whether right-handed neutrino suggested to generate SUSY in TGD framework could be the key entity in fermiogenesis.

The remaining sections are devoted to Hogan's theory abot quantum fluctuations as new kind of noise and the question whether hyperbolic 3-manifolds emerging naturally in Zero Energy Ontology might be useful in TGD inspired cosmology and explain some redshift anomalies.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. Pdf representation of same files serving as a kind of glossary can be found at `http://tgdtheory.fi/tgdglossary.pdf` [L4].

2 About The Anomalies Of The Cosmic Microwave Background

Depending on one's attitudes, the anomalies of the fluctuation spectrum of the cosmic microwave background (CMB) can be seen as a challenge for people analyzing the experiments or that of the inflationary scenario. I do not pretend to be deeply involved with CMB. What interests me is whether the replacement of inflation with quantum criticality and $\hbar$ changing phase transitions could provide fresh insights about fluctuations and the anomalies of CMB. In the following I try first to explain to myself what the anomalies are and after that I will consider some TGD inspired crazy (as always) ideas. My motivations for commuting these ideas are indeed strong: the consideration of the anomalies led to a generalization of the notion of conformal QFT to what might be called symplectic QFT having very natural place also in quantum TGD proper.

2.1 Background

Consider first some background.

1. The fluctuations of CMB reflect directly the fluctuations of energy density (acoustic waves) responsible for the formation of various structures: this follows from the proportionality $\rho \propto T^4$: one has $\Delta T/T \propto \Delta\rho/\rho \propto \Phi$, Φ is gravitational potential created by the density fluctuations. The spectrum reflects the situation as thermal photons decoupled from matter and the matter became transparent to photons. The radiation comes from the sphere of last scattering S^2, which corresponds to the setting on of transparency and only Thomson scattering can affect the radiation after that time. For short angular distances the 2-point correlation functions at S^2 for the fluctuations are suppressed: this is due to a rapid increase of photon free path during the transition making possible exponential damping of the fluctuations of energy density for angular separation $\theta < 1$ degree at which the amplitude is maximum. Quite generally, at the maxima of correlation function the photons almost decouple from the acoustic fluctuations.

2. The analysis of fluctuation spectrum of CMB in general relativistic context requires a solution of Einstein's equations for small perturbations of Robertson Walker metric in presence of matter. It is convenient to decompose the perturbation of the metric Robertson-Walker coordinates using representations of rotation group [E5]. The perturbation of g_{tt} is scalar, the perturbation of g_{ti} decomposes to a gradient of a scalar and rotor of a vector, and the perturbation of g_{ij} corresponds to a scaling of the 3-metric represented by a scalar, double gradient of scalar, and genuinely tensorial part corresponding to classical gravitational radiation. From the four scalar modes two can be eliminated as mere coordinate changes without actual physical content. It is believed that only the scalar perturbations and tensor perturbation are significant. For the WMAP data only scalar perturbations matter.

3. Scalar fluctuations can be divided to two classes. For adiabatic fluctuations the fluctuation of the energy density for a given particle species is proportional to the energy density associated with the species with a common constant of proportionality. When curvature scalar vanishes these fluctuations do not affect the curvature scalar. Inflationary scenario predicts adiabaticity. For iso-curvature fluctuations the sum of the fluctuations associated with different particles vanishes: cosmic strings predict this kind of spectrum. The detailed spectrum of the peaks for 2-point correlation functions is consistent with adiabaticity and excludes cosmic strings in sense of GUTs.

4. The predictions of the inflationary scenario follow from the assumption that fluctuations correspond to primordial quantum fluctuations of inflaton field which expanded with an exponential rate to macroscopic fluctuations during the inflationary period. The spectrum of perturbations is assumed to be Gaussian and to obey approximate scale invariance [E1]. Gaussianity holds true in 3-D momentum space and states that correlation function for the fluctuations of the energy density is proportional to 3-D delta function in momentum space. In other words, the Fourier components of the density perturbation are statistically independent. The coefficient of delta function can depend on the magnitude of 3-momentum.

For exact scale invariance it would be constant. This invariance is however broken and the multiplying function is a power k^{1-n_s} of the length of the wave vector, where n_s is so called spectral index. Spectral index has been deduced from WMAP data been measured and differs slightly from unity: $n_s = .960 \pm .0014$. Gaussian distribution contains as a free parameter the scale r of the perturbations and the observed amplitude $r = \Delta T/T \simeq 10^{-5}$ of fluctuations would reflect primordial initial conditions in energy scale about 10^{-3} times Planck mass, which has interpretation as gauge unification scale in GUTs. I am not sure whether the theories can really predict the value of r.

2.2 Anomalies Of CMB

There are several anomalies associated with CMB corresponding to the power spectrum of fluctuations and 2-point correlation function as a function of the angle difference θ between points of the sphere of last scattering. There is also some evidence for the failure of Gaussianity reflecting itself as a non-vanishing of 3-point correlation functions.

Consider first fluctuation spectrum, or formally 1-point correlation functions for what is essentially gravitational potential due to fluctuations in Newtonian gauge.

1. There is dipole term in the spectrum identifiable in terms of motion of the galaxy cluster containing Milky Way relative to the reference frame of the CMB. The cluster appears to be moving with velocity 627 ± 22 km/s in the direction of galactic longitude $(l = 264.4, b = 48.4)$ degrees [E2].

2. Hemispherical power asymmetry [E21] means that the amplitude of the fluctuations is not same at the opposite sides of the galactic plane (rather near to ecliptic plane): the difference in the amplitude is about 10 per cent. This does not mean that the mean value of temperature would differ at the opposite sides. The anomaly can be parameterized by a deviation of the amplitude from constant by an additive dipole term of amplitude.114 and in the direction (l, b)= (225, -27) degrees in galactic coordinates. Freeman suggest that the asymmetry can be eliminated for $l \leq 8$ by a slight modification of the CMB dipole [E23]. In the average sense this might hold true since dipole term has odd parity. The temperature fluctuations are also stronger in southern than northern galactic hemisphere and there is a peculiar cold spot at southern hemisphere. Dipole term cannot eliminate this kind of anomalies. One might hope that the elimination of the galactic foreground - when done properly - might eliminate this asymmetry. The subtraction of the contribution from the galactic plane affects in the first approximation only the even harmonics: this would affect the interference pattern between even and odd harmonics.

3. There is also an anomaly christened as axis of evil.

   (a) One can assign to the l: th contribution a unique axis maximizing angular momentum dispersion and these directions turn out to be very near to each other for $l = 2$ and $l = 3$ contributions [E13]. De Oliveiro Costa *et al* noticed that this anomaly could be understood if the Universe has a compact direction in this direction of size of order horizon radius. This explanation is ruled out by other tests, including the absence of matched circles. The modification of the contribution from galactic plane would affect the direction assignable to $l = 2$ harmonic but would not affect considerably $l = 3$ contribution. Hence this effect might be due a wrong subtraction.

   (b) The contribution from the harmonics with angular momentum l can be characterized in terms of l unit vectors: what one does is essentially expression of the contribution as a product of the direction cosines between radial unit vector and l unit vectors [E19]. $l = 2$ harmonics defined two vectors of this kind and their cross product defines what is called an area vector. For $l = 3$ there are three vectors of this kind and one can define three area vectors. It turns out that the planes defined by $l = 2$ area vector and two $l = 3$ area vectors are very near to each other and nearly orthogonal to the plane of ecliptic (and thus also galactic plane). These vectors are in reasonable approximation in galactic plane and aligned with the direction of CMB dipole whereas the direction.

The direction of the third $l = 3$ area vector deviates about 10 degrees from the normal of the galactic plane.

Again the smallness of $l = 2$ contribution raises the question whether the dipole correction and galactic foreground subtraction are done properly. Freeman and collaborators [E23] have proposed that a proper subtraction of CMB dipole might allow to get rid of this anomaly. According to [E20] this is probably not possible. In the case of $l = 3$ harmonics galactic subtraction affecting only even harmonics should not have any appreciable effect. The presence of cold spot near Galactic center and hot spot near Gum Nebula, both in the galactic plane, could also relate to the fact that the area vector is aligned with galactic plane.

Consider next two-point correlation functions.

1. The function $C(\theta)$ is obtained by averaging the fluctuations for all pairs of points at the sphere of last scattering separated by angle θ. $C(\theta)$ with galactic cutoff vanishes for $\theta > 60$ degrees the correlation function vanishes in good approximation [E20]. There is also a strange finding [E24] suggesting a strong correlation between the fluctuation spectrum and 2-point correlation function. Large scale cutoff of $C(\theta)$ in the full-sky maps without galactic cutoff is absent while cut-sky maps with the galactic contribution masked are anomalous. The galactic cut is also almost equivalent with the masking of the cold and hot spot assignable to the galactic plane. Accepting the hot and cold spots in the galactic plane as real would give large scale correlations of 2-point correlation functions and vice versa. Also the subtraction of the anomalous quadrupole and octopole contributions from the 1-point correlation function brings back the large scale power. It is also essential that the multipole vectors of these contributions are nearly parallel. Hence it seems that one can choose between two evils: either the power cutoff at large scales or the axis of evil.

2. For low l harmonics statistical isotropy assumption fails [E20]. This means that the correlation functions $\langle a_{lm}a_{l_1,-m_1}\rangle$ in the expansion of ΔT in terms of spherical harmonics $Y_{l,m}$ taken over temporal ensemble are not of form $C_l\delta_{l,l_1}\delta_{m,m_1}$, where C_l would define coefficients of $C(\theta)$ in terms of $P_l(\theta)$. Quadrupole terms ($l = 2$) are also anomalously small.

There are also other anomalous correlations.

1. Unexpectedly high correlation between temperature and E-mode polarization caused by Thomson scattering of CMB photons can be seen as an evidence for a large optical depth and very early star formation [E17].

2. Gaussianity predicts that three-point correlation functions for density fluctuations vanish. Hence also three-point correlation functions at the sphere of the last scattering should vanish. There is some evidence that this is not the case [E44]: the proposed deviation from Gaussianity is parameterized by writing the perturbation of the gravitational potential in the form $\Phi = \Phi_L + f_{NL}(\Phi_L^2 - \langle\Phi_L^2\rangle)$.

2.3 What TGD Could Say About The Anomalies?

TGD cosmology involves several new elements. Super-conformal invariance generalizes in TGD framework and one can wonder whether the fluctuations at the sphere of the last scattering could be described in terms of conformal field theory. It turns out that symplectic QFT based on the analogs of fusion rules is more natural in TGD framework. There are p-adic and dark matter hierarchies realized in terms of book like structure of embedding space with levels labeled by Planck constant with gravitational Planck constant assignable to flux tubes mediating gravitational interactions and having gigantic values so that quantum coherence in cosmological scales is possible. Zero energy ontology implies that time like entanglement in cosmic time scales assignable to gravitational interaction is possible so that the notion of state function reduction in astrophysical and cosmic time scales might make sense. Hence one could (just for fun) wonder whether the strange correlations between local galactic and solar geometry and density fluctuations at surface of large scattering might be real after all.

2.3.1 Implications of p-adic and dark matter hierarchies

Consider next the possible implications of p-adic and dark matter hierarchies.

1. In TGD framework there are two hierarchies: hierarchy of p-adic space-time sheets and hierarchy of Planck constants. p-Adic length scales are defined as $L_p \propto \sqrt{p}$, where $p \simeq 2^k$ is prime and k is positive integer. $L(151)$ corresponds in good approximation to 10 nm, cell membrane thickness. The hierarchy of Planck constants reflect the book like structure of the generalized embedding space consisting of almost copies of $M^4 \times CP_2$ glued together like pages of book along common back. The proposed structure of embedding space can be understood as a geometric correlate for the choice of quantization axes at the embedding space level inducing it also at the level of configuration space (world of classical worlds). There are preferred quantization axes associated with both M^4 and CP_2 degrees of freedom. In the case of M^4 this means preferred plane M^2 defining a quantization axis of spin and in the case of CP_2 preferred homologically non-trivial geodesic sphere defining quantization axis of color isospin. This means breaking of symmetries at particular sector of the embedding space but since the "world of classical worlds" (WCW) is union over different choices of quantization axes, symmetries remain intact as a whole. It would seem that quantum measurement with new quantization axis means a tunnelling from between this kind of sectors.

2. It is important to notice that in TGD Universe the fluctuations emerge during the quantum criticality at the time of decoupling rather than developing from primordial fluctuations as in the case of inflationary cosmology. This kind of periods would be quite general since the smooth cosmic expansion is in TGD Universe replaced by a sequence of quantum leaps during which Planck constant for some relevant space-time sheet increases and implies the increase of the size L of the appropriate space-time sheet scaling like $\hbar$. The same mechanism explains also the accelerated cosmic expansion taking place much later during cosmic expansion and probably corresponding to expansion for large voids of size of order 10^8 ly.

3. In TGD Universe the vanishing of the curvature scalar of 3-space (flatness) corresponds to quantum criticality associated with phase transitions changing the value of Planck constant. Robertson-Walker form of the metric, criticality constraint, and imbeddability as a vacuum extremal to $M^4 \times S^2 \subset M^4 \times CP_2$ fix the critical cosmology highly uniquely. The critical cosmology has a finite temporal duration due to the failure of the global embedding. During early phases the critical mass density behaves as $1/a^2$ which might be interpreted in terms of dominance of string like objects, which in TGD framework are identified as long magnetic flux tubes.

Can one say anything more quantitative about the situation? In particular, can one predict the scale (variance) of $\Delta T/T$?

1. There are two dimensionless numbers available: the value of the integer k characterizing p-adic length scale $L_p \propto 2^{k/2}$ characterizing the surface of the last scattering and the ratio $\hbar/\hbar_0$ of Planck constants associated with dark and visible sectors of WCW .

2. The value of the integer k characterizing p-adic length scale at the time of the transition can be estimated from the radius for the sphere of last scattering identified as radius $R = a(t)$. The transition to matter dominated Universe began in about 400, 000 years old universe. Coupling took about 120, 000 years and was finished at the age of 500, 000 years. From this one can estimate the p-adic length scale in question as light-cone proper time $a(t)/a_0 = (t/t_0)^{2/3}$ in matter dominated cosmology identifiable as curvature radius R in GRT based RW cosmology. My own estimate $a = 3 \times 10^7$ ly in [K31] gives $k \sim 355$.

3. Identifying $\Delta\rho_i$ for a given particle as the energy density $\rho_{i,d}$ of dark variant of the particle implies adiabaticity if one has $\rho_{i,d}/\rho_i = constant$. This is achieved by assuming that the energy densities scale like ρ_{tot}, that is one has $\rho_{d,i} = (\hbar/\hbar_0)^{-n}\rho_i \propto (\hbar/\hbar_0)^{-n}\ a^{-n}$. $n = 2$ is suggested by the early critical cosmology discussed [K31]. This would give $\Delta\rho_i/\rho_i = (\hbar_0/\hbar)^2$. From $\Delta T/T \simeq 10^{-5}$ one would have $r = \hbar/\hbar_0 \sim 300$. The estimate for r is not too far from $k \sim 355$, which might mean that $r = k$ holds true implying that the r would increase logarithmically with the p-adic length scale of the space-time sheet.

Consider next the anomalies from phenomenological point of view.

1. One cannot exclude the possibility that the vanishing of the two-point correlation functions for $\theta > 60$ degrees reflects the finite size of the space-time sheets. In conformal field theory approach this would mean that conformal field theory applies only inside patches at the sphere of last scattering. Suppose that the size of space-time sheets is typically of order p-adic length scale $L_p \propto \sqrt{p}$, where $p \simeq 2^k$ is prime and k is positive integer. For the surface of last scattering $L_p \equiv L(k)$ could be identified as the radius of the sphere and can be estimated from the value of light-cone proper time a at that time.

   The first guess is that only the points of the sphere for which distance is shorter than $L(k)$ can correlate. Simple elementary geometry shows that this is the case only for $\theta < 60$ degrees! The reduction of the vanishing correlation to almost kinematics must of course be taken with a big grain of salt: if the diameter of the sphere is taken to be L_p, one would have $\theta < 180$ degrees.

   The killer prediction is that the non-averaged correlation function for two fixed points of sphere obtained by averaging the fluctuations over ensemble of observations should vanish for smaller values of angular distances when points belong to different patches so that the boundaries of patches should be identifiable from CMB map.

2. As already noticed, the presence of galactic cold and hot spots and axis of evil seem to be the price to be paid for the presence of large scale power [E24]. The finite size of the space-time sheets forcing the vanishing of 2-point correlation function for large angular separations could thus conform with the non-CMB explanation of galactic cold and hot spots and allow to get rid of axis of evil. The pair of cold and hot spots indeed gives a large negative contribution to $C(\theta)$. The finite size of space-time sheets could also explain the hemispherical asymmetry and why fluctuations are stronger at the southern galactic hemisphere.

3. The particles at different pages of the “Big Book” can tunnel between the pages so that the presence of dark space-time sheets could affect the spectrum of temperature fluctuations. If dark matter is responsible for the fluctuations, the tunnelling of dark photons to visible space-time sheets and vice versa might have something to do with the fluctuations of CMB spectrum. Fractality suggests that dark space-time sheets could induce a modulation of the amplitudes of CMB proposed to explain the hemispherical asymmetries but not why the hemispheres correspond to Nothern and Southern galactic spheres. There would be kind of modulation hierarchy. This might relate to the fluctuations in the amplitude of ΔT, and the related small 10 percent deviation of the fluctuation amplitudes at Northern and Souther hemisphere.

A couple of warnings are in order.

1. The proposed mechanism does not explain the strange correlations of CMB with the local geometry. If one accepts quantum coherence in cosmic length scales predicted by the dark matter hierarchy, the choice of quantization axis in cosmic scale having direct geometric correlate in TGD Universe, could explain the asymmetries as a result of state function reduction in cosmic scale.

2. The decomposition into disjoint space-time sheets is not the only manner to explain the anomalies. It will be found that the approach based on symplectic QFT predicts with very general assumptions about 2-point functions hemispherical asymmetry. Symplectic approach might be also able explain the vanishing of $C(\theta)$ in large scales.

2.3.2 Perturbations of the critical cosmology: the naïve approach

Although the naïve formal application of perturbation theory around critical cosmology does not make sense in quantum TGD framework, one can start by looking what it would give at classical level.

1. Concerning the perturbations of the critical cosmology, a natural condition would be that only vacuum extremals of Kähler action are allowed. This means that only perturbations giving rise to 4-surfaces belonging to $M^4 \times Y^2 \subset M^4 \times CP_2$, Y^2 Lagrangian sub-manifold of CP_2, are allowed. If all small deformations of the critical cosmology are allowed, curvature scalar cannot vanish in general. In this framework the notion of adiabaticity involving statements about various particles does not have any obvious meaning whereas the notion of iso-curvature fluctuations can be formulated. The vanishing of the curvature scalar makes sense for the perturbations of RW metric representing vacuum extremals but would break the symplectic symmetry in CP_2 degrees of freedom. Note also that many-sheeted space-time and the generalization of embedding space induced by hierarchy of Planck constants are quite essential piece of TGD vision and are not taken into account in this naïve approach.

2. One can express the perturbations of the metric in terms of gradients of CP_2 coordinates and since for the unperturbed RW metric CP_2 coordinates depend on light-cone proper time only, the perturbations are gradients of CP_2 coordinates with respect to spatial coordinates so that a reduction to scalar perturbations modifying only g_{aa} and vector perturbations implying non-vanishing g_{ai} indeed takes place in the first order. Since g_{ij} remains invariant in the first order, also 3-space remains flat in this order. In second order also other modes become possible.

3. The absence of other than scalar modes in the first order means that classical gravitons are absent in this order. Does this mean that also quantal gravitons are absent in the first order so that the B mode polarization would be smaller than expected? Probably not: the basic reason for developing the vision about physics as the geometry of WCW was the total failure of the perturbative path integral approach theory in TGD framework. Previous considerations also force to ask whether the phase transitions of dark gravitons to ordinary gravitons could be an an essential element of detection of gravitons and mean that dark graviton with very large energy as compared to the wavelength transforms to a bunch of ordinary gravitons. This might lead to the erratic elimination of the graviton signal as a noise. One can also consider the possibility that dark gravitons with very long wave lengths transform to ordinary gravitons with much shorter wavelengths.

2.3.3 Could super-conformal field theory at sphere of last scattering describe the fluctuations?

I have already earlier [K31] proposed that CMB spectrum might be understood in terms of conformal field theory. If some variant of conformal field theory works, the general prediction is the breaking of conformal invariance meaning the appearance of the counterpart of the spectral index from the breaking of conformal symmetry by the generation of central extension to super-conformal algebra. In this framework $1 - n_s$ corresponds to an anomalous dimension having a discrete spectrum in conformal theories and known once the representation of Super Virasoro algebra is known. It would not be surprising if n_s would depend on the value of $\hbar$, which defines a quantum phase q playing also a key role in conformal field theories. Second important prediction would be that 3-point correlation functions are predictable and non-vanishing unless the conformal field theory in question is not free. This would allow the possibility of non-Gaussian behavior.

It however seems that CQFT need not be quite correct idea. Rather, a symplectic variant of conformal field theory is natural in TGD framework and could be used to characterize the ground state in terms of n-points functions. The basic objection against the use of conformal field theory is that it should apply to the construction of physical states pairs of positive and negative energy states and considering thus non-vacuum fluctuations of space-time surfaces around vacuum extremals. Now one is considering vacuum states with respect to Noether charges expressed as functionals in the space of vacuum extremals. Since symplectic transformations are symmetries of the vacuum extremals, a symplectic analogy of conformal field theory might be a more appropriate approach. In the following this argument is made more precise.

1. One must consider small perturbations of the critical cosmology which are also vacuum extremals. This means that the perturbations correspond to surface $X^4 \subset M^4 \times Y^2$, where Y^2 corresponds to Lagrangian sub-manifold of CP_2 having vanishing induced Kähler form. If one

poses no other conditions the vacuum extremals possess symplectic transformations of CP_2 leaving given Y^2 invariant as symmetries. These transformations relate closely to so called super-symplectic symmetries which are basic super-conformal symmetries of quantum TGD besides Kac-Moody type symmetries assignable to light-like 3-surfaces identified as basic dynamical objects. Also symplectic (or rather contact-) transformations of $r_M = constant$ sphere of light-cone boundary act as this kind of symmetries which raises the question whether the analog of conformal field theory based having the symplectic group of light-cone boundary as symmetries might be a proper manner to characterize the vacuum degeneracy in quantum TGD.

2. Could conformal field theory possessing these symmetries defined at the sphere of last scattering (S^2) or - as suggested by basic structure of quantum TGD - at the boundary of 3-D light-cone connecting S^2 to the observer's position - describe the quantum criticality? The hope raised by the fact that critical cosmology is fixed the by the criticality condition without any reference to matter is that the correlation functions could be deduced from universality without any reference to elementary particle physics.

   (a) The naïve guess would be that the deviations of CP_2 complex coordinates ξ^k from their values at S^2 should be taken as primary dynamical variables. Unfortunately, the assumption that ξ^k are holomorphic functions of the complex coordinate of the sphere of last scattering would not be consistent with the vacuum extremal property. The use of CP_2 coordinates as dynamical variables is not consistent with general coordinate invariance unless one chooses some special coordinates. This is possible since selection of preferred quantization axis selects preferred complex coordinates unique modulo $U(2) \subset SU(3)$ rotations represented linearly. The simplest manner to achieve general coordinate invariance is by using the gravitational potential defined as the perturbation $\Delta g_{aa} = \Delta(s_{k\bar{l}}\partial_a\xi^k\partial_a\overline{\xi}^l)$. All perturbations of R-W metric can be arranged to the representation of rotation group corresponding to two scalars, vector, and traceless tensor. Unfortunately, the deviations of metric do not however define conformal fields in S^2. They could however define symplectic fields. It seems that conformal field theory approach requires the expression of Δg_{aa} in terms of primary conformal fields, say various currents, and this looks too complicated.

   (b) The radial light-like coordinate r_M for the light-cone boundary plays a role analogous to that of complex coordinate for Kac-Moody representations at like 3-surfaces and for super-symplectic representations at light-cone boundary. In this case all vacuum extremals are allowed and the symplectic transformations of $S^2 \times CP_2$ localized with respect to r_M would act as analogos of conformal symmetries. In quantum TGD proper this could quite well make sense but in the recent situation only a QFT at S^2 is needed and light-like conformal invariance does not seem to say anything about the behavior of the correlation functions of temperature fluctuations at S^2.

2.3.4 Could a symplectic analog of conformal field theory work?

Symplectic symmetries of $\delta M^4_+ \times CP_2$ (light-cone boundary briefly) inspire the question whether a symplectic analog of conformal field theory at S^2 could dictate the correlation functions. Therefore it makes sense to play with the idea what symplectic QFT could look like and what one could conclude about the predictions of "symplectic QFT" in the recent situation.

1. In quantum TGD the symplectic transformation of the light-cone boundary would induce action in the "world of classical worlds" (light-like 3-surfaces). In the recent situation it is convenient to regard perturbations of CP_2 coordinates as fields at the sphere of last scattering (call it S^2) so that symplectic transformations of CP_2 would act in the field space whereas those of S^2 would act in the coordinate space just like conformal transformations. The deformation of the metric would be a symplectic field in S^2. The symplectic dimension would be induced by the tensor properties of R-W metric in R-W coordinates: every S^2 coordinate index would correspond to one unit of symplectic dimension. The symplectic invariance in CP_2 degrees of freedom is guaranteed if the integration measure over the vacuum deformations is symplectic invariant. This symmetry does not play any role in the sequel.

2. For a symplectic scalar field $n \geq 3$-point functions with a vanishing anomalous dimension would be functions of the symplectic invariants defined by the areas of geodesic polygons defined by subsets of the arguments as points of S^2. Since n-polygon can be constructed from 3-polygons these invariants can be expressed as sums of the areas of 3-polygons expressible in terms of symplectic form. n-point functions would be constant if arguments are along geodesic circle since the areas of all sub-polygons would vanish in this case. The decomposition of n-polygon to 3-polygons brings in mind the decomposition of the n-point function of conformal field theory to products of 2-point functions by using the fusion algebra of conformal fields (very symbolically $\Phi_k\Phi_l = c_{kl}^m\Phi_m$). This intuition seems to be correct.

3. Fusion rules stating the associativity of the products of fields at different points should generalize. In the recent case it is natural to assume a non-local form of fusion rules given in the case of symplectic scalars by the equation

$$\Phi_k(s_1)\Phi_l(s_2) = \int c_{kl}^m f(A(s_1,s_2,s_3))\Phi_m(s)d\mu_s \quad . \tag{2.1}$$

   Here the coefficients c_{kl}^m are constants and $A(s_1,s_2,s_3)$ is the area of the geodesic triangle of S^2 defined by the sympletic measure and integration is over S^2 with symplectically invariant measure $d\mu_s$ defined by symplectic form of S^2. Fusion rules pose powerful conditions on n-point functions and one can hope that the coefficients are fixed completely.

4. The application of fusion rules gives at the last step an expectation value of 1-point function of the product of the fields involves unit operator term $\int c_{kl}f(A(s_1,s_2,s))Idd\mu_s$ so that one has

$$\langle\Phi_k(s_1)\Phi_l(s_2)\rangle = \int c_{kl}f(A(s_1,s_2,s))d\mu_s \quad . \tag{2.2}$$

   Hence 2-point function is average of a 3-point function over the third argument. The absence of non-trivial symplectic invariants for 1-point function means that $n=1$- an are constant, most naturally vanishing, unless some kind of spontaneous symmetry breaking occurs. Since the function $f(A(s_1,s_2,s_3))$ is arbitrary, 2-point correlation function can have both signs. 2-point correlation function is invariant under rotations and reflections.

CMB data suggest breaking of rotational and reflection symmetries. A possible mechanism of spontaneous symmetry breaking is based on the observation that in TGD framework the hierarchy of Planck constants assigns to each sector of the generalized embedding space a preferred quantization axes. The selection of the quantization axis is coded also to the geometry of "world of classical worlds", and to the quantum fluctuations of the metric in particular. Clearly, symplectic QFT with spontaneous symmetry breaking would provide the sought-for really deep reason for the quantization of Planck constant in the proposed manner.

1. The coding of angular momentum quantization axis to the generalized embedding space geometry allows to select South and North poles as preferred points of S^2. To the three arguments s_1,s_2,s_3 of the 3-point function one can assign two squares with the added point being either North or South pole. The difference

$$\Delta A(s_1,s_2,s_3) \quad \equiv \quad A(s_1,s_2,s_3,N) - A(s_1,s_2,s_3,S) \tag{2.3}$$

   of the corresponding areas defines a simple symplectic invariant breaking the reflection symmetry with respect to the equatorial plane. Note that ΔA vanishes if arguments lie along a geodesic line or if any two arguments coincide. Quite generally, symplectic QFT differs from conformal QFT in that correlation functions do not possess singularities.

2. The reduction to 2-point correlation function gives a consistency conditions on the 3-point functions

$$\begin{aligned} \langle(\Phi_k(s_1)\Phi_l(s_2))\Phi_m(s_3)\rangle &= c_{kl}^r \int f(\Delta A(s_1,s_2,s))\langle\Phi_r(s)\Phi_m(s_3)\rangle d\mu_s \\ &= \quad (2.4) \\ c_{kl}^r c_{rm} \int f(\Delta A(s_1,s_2,s)) f(\Delta A(s,s_3,t)) d\mu_s d\mu_t \ . \quad (2.5) \end{aligned}$$

   Associativity requires that this expression equals to $\langle\Phi_k(s_1)(\Phi_l(s_2)\Phi_m(s_3))\rangle$ and this gives additional conditions. Associativity conditions apply to $f(\Delta A)$ and could fix it highly uniquely.

3. 2-point correlation function would be given by

$$\langle\Phi_k(s_1)\Phi_l(s_2)\rangle = c_{kl} \int f(\Delta A(s_1,s_2,s)) d\mu_s \quad (2.6)$$

4. There is a clear difference between $n > 3$ and $n = 3$ cases: for $n > 3$ also non-convex polygons are possible: this means that the interior angle associated with some vertices of the polygon is larger than π. $n = 4$ theory is certainly well-defined, but one can argue that so are also $n > 4$ theories and skeptic would argue that this leads to an inflation of theories. TGD however allows only finite number of preferred points and fusion rules could eliminate the hierarchy of theories.

5. To sum up, the general predictions are following. Quite generally, for $f(0) = 0$ n-point correlation functions vanish if any two arguments coincide which conforms with the spectrum of temperature fluctuations. It also implies that symplectic QFT is free of the usual singularities. For symmetry breaking scenario 3-point functions and thus also 2-point functions vanish also if s_1 and s_2 are at equator. All these are testable predictions using ensemble of CMB spectra.

Since number theoretic braids are the basic objects of quantum TGD, one can hope that the n-point functions assignable to them could code the properties of ground states and that one could separate from n-point functions the parts which correspond to the symplectic degrees of freedom acting as symmetries of vacuum extremals and isometries of WCW

1. This approach indeed seems to generalize also to quantum TGD proper and the n-point functions associated with partonic 2-surfaces can be decomposed in such a way that one obtains coefficients which are symplectic invariants associated with both S^2 and CP_2 Kähler form.

2. Fusion rules imply that the gauge fluxes of respective Kähler forms over geodesic triangles associated with the S^2 and CP_2 projections of the arguments of 3-point function serve basic building blocks of the correlation functions. The North and South poles of S^2 and three poles of CP_2 can be used to construct symmetry breaking n-point functions as symplectic invariants. Non-trivial 1-point functions vanish also now.

3. The important implication is that n-point functions vanish when some of the arguments coincide. This might play a crucial role in taming of the singularities: the basic general prediction of TGD is that standard singularities should be absent and this mechanism might realize this expectation.

Next some more technical but elementary first guesses about what might be involved.

1. It is natural to introduce the moduli space for n-tuples of points of the symplectic manifold as the space of symplectic equivalence classes of n-tuples. In the case of sphere S^2 convex

n-polygon allows $n+1$ 3-sub-polygons and the areas of these provide symplectically invariant coordinates for the moduli space of symplectic equivalence classes of n-polygons (2^n-D space of polygons is reduced to $n+1$-D space). For non-convex polygons the number of 3-sub-polygons is reduced so that they seem to correspond to lower-dimensional sub-space. In the case of CP_2 n-polygon allows besides the areas of 3-polygons also 4-volumes of 5-polygons as fundamental symplectic invariants. The number of independent 5-polygons for n-polygon can be obtained by using induction: once the numbers $N(k,n)$ of independent $k \leq n$-simplices are known for n-simplex, the numbers of $k \leq n+1$-simplices for $n+1$-polygon are obtained by adding one vertex so that by little visual gymnastics the numbers $N(k,n+1)$ are given by $N(k,n+1) = N(k-1,n)+N(k,n)$. In the case of CP_2 the allowance of 3 analogs $\{N,S,T\}$ of North and South poles of S^2 means that besides the areas of polygons (s_1,s_2,s_3), (s_1,s_2,s_3,X), (s_1,s_2,s_3,X,Y), and (s_1,s_2,s_3,N,S,T) also the 4-volumes of 5-polygons (s_1,s_2,s_3,X,Y), and of 6-polygon (s_1,s_2,s_3,N,S,T), $X,Y \in \{N,S,T\}$ can appear as additional arguments in the definition of 3-point function.

2. What one really means with symplectic tensor is not clear since the naïve first guess for the n-point function of tensor fields is not manifestly general coordinate invariant. For instance, in the model of CMB, the components of the metric deformation involving S^2 indices would be symplectic tensors. Tensorial n-point functions could be reduced to those for scalars obtained as inner products of tensors with Killing vector fields of $SO(3)$ at S^2. Again a preferred choice of quantization axis would be introduced and special points would correspond to the singularities of the Killing vector fields.

   The decomposition of Hamiltonians of WCW expressible in terms of Hamiltonians of $S^2 \times CP_2$ to irreps of $SO(3)$ and $SU(3)$ could define the notion of symplectic tensor as the analog of spherical harmonic at the level of WCW . Spin and gluon color would have natural interpretation as symplectic spin and color. The infinitesimal action of various Hamiltonians on n-point functions defined by Hamiltonians and their super counterparts is well-defined and group theoretical arguments allow to deduce general form of n-point functions in terms of symplectic invariants.

3. The need to unify p-adic and real physics by requiring them to be completions of rational physics, and the notion of finite measurement resolution suggest that discretization of also fusion algebra is necessary. The set of points appearing as arguments of n-point functions could be finite in a given resolution so that the p-adically troublesome integrals in the formulas for the fusion rules would be replaced with sums. Perhaps rational/algebraic variants of $S^2 \times CP_2 = SO(3)/SO(2) \times SU(3)/U(2)$ obtained by replacing these groups with their rational/algebraic variants are involved. Tedrahedra, octahedra, and dodecahedra suggest themselves as simplest candidates for these discretized spaces. Also the symplectic moduli space would be discretized to contain only n-tuples for which the symplectic invariants are numbers in the allowed algebraic extension of rationals. This would provide an abstract looking but actually very concrete operational approach to the discretization involving only areas of n-tuples as internal coordinates of symplectic equivalence classes of n-tuples. The best that one could achieve would be a formulation involving nothing below measurement resolution.

4. This picture based on elementary geometry might make sense also in the case of conformal symmetries. The angles associated with the vertices of the S^2 projection of n-polygon could define conformal invariants appearing in n-point functions and the algebraization of the corresponding phases would be an operational manner to introduce the space-time correlates for the roots of unity introduced at quantum level. In CP_2 degrees of freedom the projections of n-tuples to the homologically trivial geodesic sphere S^2 associated with the particular sector of CH would allow to define similar conformal invariants. This framework gives dimensionless areas (unit sphere is considered). p-Adic length scale hypothesis and hierarchy of Planck constants would bring in the fundamental units of length and time in terms of CP_2 length.

These findings raise the hope that quantum TGD is indeed a solvable theory. Even it one is not willing to swallow any bit of TGD, the classification of the symplectic QFTs remains a fascinating mathematical challenge in itself. A further challenge is the fusion of conformal QFT and symplectic QFT in the construction of n-point functions. One might hope that conformal and symplectic fusion rules can be treated separately.

2.3.5 What symplectic QFT tells about fluctuations?

It is interesting to look what one can say about the CMB assuming symplectic QFT using the proposed poor man's formulation.

The general predictions are that all n-point functions are non-vanishing so that Gaussianity fails to be true. In the symmetric scenario there is no breaking of rotational and reflection symmetries. In symmetric breaking scenario both breakings are present.

Consider first 2-point correlation functions.

1. The averaged 2-point correlation function $C(\theta)$ is obtained as

$$\begin{aligned} C(\theta) &= \langle \Phi(s_1)\Phi(s_2)\rangle = \sum_n f_n \langle \int [\Delta A(s_1,s_2,s)]^n d\mu_s\rangle \ , \\ \Delta A(s_1,s_2,s) &= A(s_1,s_2,s,N) - A(s_1,s_2,s,P) \ . \end{aligned} \tag{2.7}$$

2. If $f(\Delta A)$ is odd function of $\Delta A = A(s_1,s_2,s_3,N) - A(s_1,s_2,s_3,P)$, the first order term of the 3-point function changes sign under reflection of the first two arguments with respect to the equatorial plane and same holds true for all odd powers of ΔA as a simple argument shows. Same holds true for the 2-point correlation function so that its average over all points with same angular distance vanishes giving $C(\theta) = 0$. $C(\theta)$ is completely determined by the even part of f and one can write the averaged correlation function as

$$C(\theta) = \sum_n f_{2n} \langle \int [\Delta A(s_1,s_2,s)]^{2n} d\mu_s\rangle \ . \tag{2.8}$$

   Thus the rotational averages of the numerically calculable even "moments" $\int [\Delta A(s_1,s_2,s)]^{2n} d\mu_s$ determine $C(\theta)$.

3. Since $C(\theta)$ has also negative values, some of the coefficients f_{2n} must be negative. The variation of the signs of the coefficients is also necessary to explain the presence of positive maxima and negative minima in $C(\theta)$.

4. An open question is whether the smallness of $C(\theta)$ for angle separation larger than 60 degrees could be understood from symplectic invariance alone.

3-point correlation functions are certainly non-trivial and this means means a non-Gaussian behavior. Non-vanishing 2-point functions are averages of the 3-point functions involving identity operator with respect to third argument multiplied by 4π. Hence the non-Gaussian behavior is significant effect. For 3-point functions not involving identity operator the coefficients c_{klm} could be smaller.

Consider next the fluctuations.

1. It would be nice if temperature fluctuations could be interpreted as 1-point functions rather than particular fluctuations. This is not the case since the only reasonable candidate would be obtained in terms of the area of the degenerate geodesic triangle spanned by s and poles. This means that one must interpret the data as fluctuations rather than averages of fluctuations unless one is ready to break the symmetry by shifting slightly the second preferred point, say South Pole.

2. The intuitive notions about distribution for the fluctuations and amplitude of fluctuations are not readily expressible in terms of n-point correlation functions since the moments $\langle \Phi(s)^k\rangle$ vanish identically. One can however perform smoothing out of these quantities and replace

the quantity $\langle \Phi(s)^k \rangle$ with $\int \langle \prod_i \Phi(s_i) \rangle \prod_k d\mu_{s_k}/A^n$, where the integrations are over a small disk of area A around point s. This gives a well defined variance and one can speak about fluctuation amplitude in a given resolution defined by A. The moments define in a given resolution what the probability distribution for the fluctuations means.

3. This definition allows to formulate what the evidence for the hemispherical asymmetry for the probability distribution of fluctuations could mean. Hemispherical asymmetry is obtained in the smooth out sense if the two-point correlation functions with arguments differing by a reflection with respect to equatorial plane are not identical: that is if $f(\Delta A)$ contains both even and odd coefficients f_n. The reason is that the sign of ΔA changes in the reflection. This could be tested by considering the counterpart of $C(\theta)$ defined by taking only average with respect to point pairs in upper/lower hemisphere and comparing the results.

To sum ump, the breaking of the rotational symmetry and parity breaking via a selection of a preferred equatorial plane conform with the general properties of the physical correlation functions and it remains to be seen whether fusion rules force f to have both odd and even parts necessary in obtain to obtain the breaking of reflection symmetry. The challenge is to understand whether the correlation between cosmic and local geometries (equatorial plane of S^2 and galactic plane) is a pure accident or whether there is something much deeper involved.

2.3.6 Could cosmic quantum coherence explain the correlation of the quantum fluctuations at surface of last scattering with galactic geometry?

The idea about hierarchy of Planck constants was inspired by the finding that the orbits of inner and outer planets could be regarded in a reasonable approximation as Bohr orbits but with Planck constant which was gigantic and was for outer planets smaller than for the 4 inner planets by a factor of 1/5 [K30]. For Jupiter with $v_0/5$ principal quantum number would be $n_P = 2$ and Mars could be thought to have $n_P = 1$ for $v_0/5$. The gigantic value of the Planck constant at the flux tubes mediating gravitational interactions implies quantum coherence in cosmic scales and this could allow a radically new interpretation of CMB anomalies. In particular, it could explain why the preferred equatorial plane of the sphere of last scattering predicted by symplectic QFT with spontaneous symmetry breaking is near to the galactic plane.

1. Gravitational Planck constant associated with the flux tubes mediating gravitational interactions has a gigantic value, which quantum coherence in cosmological scales. This forces to ask whether the measurement of CMB background should be considered as a quantum measurement in cosmic scales and whether its outcome could be analogous to the state function reduction at the level of particle physics as far as dark space-time sheets are considered. If dark matter dictates the behavior of visible matter one must consider the possibility that quantum measurement in dark scales could dramatically affect the geometric past in cosmic scales. On the other hand, the CMB measurements as such are only about distribution of ordinary photons and can only tell which quantum fluctuation pattern has been selected in quantum measurement in dark matter scales.

2. The situation at quantum criticality would correspond to a superposition of quantum fluctuations having in accordance with zero energy ontology time-like entanglement with the "observer". This entanglement correlates the states of observer with the quantum fluctuations. Observer could be a dark matter system assignable to galaxy, say the field body of galactic system with gigantic Plank constant connecting observer with the sphere of last scattering which in turn might be entangled with the solar system. The question is whether the time-like entanglement correlates some geometric properties of the observing system (say various directions like normal of the ecliptic or galactic plane) with the geometric properties of the quantum fluctuation spectrum (say the direction of the quantization axis defining equatorial asymmetry)?

3. Could one imagine that "we" as observers are entangled with the possible states of the galactic gravito-magnetic body in turn entangled gravitationally with the quantum fluctuations at the sphere of last scattering and that the measurement of the state of galactic system telling the direction of galactic plane, etc... selects also the dark quantum fluctuation in the geometric

past. If so, the selection of quantization axes for fluctuations would be same for the observer and sphere of last scattering. If the choice is dictated by the observer, the breaking of rotational symmetry and parity symmetry and choice of galactic plane as preferred plane would be induced by quantum measurement. Note that this does not lead to any obvious contradictions since the spheres of last scattering are in principle different for observers at different positions of the Universe. If this interpretation is correct, the strange anomalies of CMB would provide a rather dramatic verification for the Wheeler's idea about participatory Universe.

2.3.7 Axis of Evil as a memory from primordial cosmology?

Axis of Evil is very interesting CMB anomaly (thanks for Sky Darmos for mentioning it in FB discussion). It has been even proposed that it forces Earth-centeredness. According to the Wikipedia article (see `http://tinyurl.com/yb6nabw4`):

The motion of the solar system, and the orientation of the plane of the ecliptic are aligned with features of the microwave sky, which on conventional thinking are caused by structure at the edge of the observable universe. Specifically, with respect to the ecliptic plane the "top half" of the CMB is slightly cooler than the "bottom half"; furthermore, the quadrupole and octupole axes are only a few degrees apart, and these axes are aligned with the top/bottom divide.

Axis of Evil is indeed really strange looking finding. To my view it does not however bring pre-Keplerian world view back but is related to the possibility of quantum coherence even in cosmological scales predicted by TGD. It would also reflect the situation during very early cosmology, which in TGD framework is cosmic string dominated.

1. The hierarchy of Planck constants $h_{eff} = n \times h_0$ ($h = 6 \times h_0$ is a good guess) implies the existence of space-time sheets with arbitrary large size serving as quantum coherent regions. $h_{eff} = h_{gr}$ assignable to flux tubes mediating gravitational interaction the value of h_{eff} can be gigantic. One has $h_{gr} = GMm/v_0$, where M and m are masses such that M can be solar mass or even larger mass and $v_0 < c$ has dimensions of velocity [L16] [K3].

2. Cosmic strings dominated the very early TGD inspired cosmology. They have 2-D projections to M^4 and CP_2 so that GRT is not able to describe them. During the analog of inflationary period the dimension of M^4 projection became D=4 and cosmic strings became magnetic flux tubes. Ordinary GRT space-time emerged and GRT started to be a reasonable approximation as QFT limit of TGD.

3. Quantum coherence make possible long range correlations. One correlation of this kind could be occurrene of cosmic strings which are *nearly parallel* in even cosmic scales or more precisely nearly parallel at the time when the TGD counterpart of inflation occurred and the ordinary space-time emerged and cosmic strings thickened to magnetic flux tubes - a process directly corresponding to cosmic expansion. This time corresponds in standard cosmology the end of inflationary period.

   The volume that we observe via CMB now would correspond to a rather small volume at the end of the period when ordinary GRT space-time emerged and it is not too difficult to imagine that in this volume the cosmic strings would have formed a bundle nearly parallel cosmic strings. This property would have been preserved in good approximation during expansion. For instance, angular momentum conservation would have taken care of this if the galaxies along long cosmic strings had angular momenta in parallel: there is indeed evidence for this. Turning of cosmic string to a different direction would require a lot of angular momentum since also the galaxies should be turned at the same time.

4. Cosmic strings thicknened to flux tubes would contain galaxies - pearls in necklace is good metaphor. Galaxies would be local tangles of flux tubes with topology of dipole type magnetic field in reasonable approximation. Also stars and planets would have formed in the similar manner. This leads to a rather detailed model for galaxy formation [L20].

3 Simulating Big Bang In Laboratory

Ultra-high energy collisions of heavy nuclei at Relativistic Heavy Ion Collider (RHIC) can create so high temperatures that there are hopes of simulating Big Bang in laboratory. The experiment with PHOBOS detector [C7] probed the nature of the strong nuclear force by smashing two Gold atoms together at ultrahigh energies. The analysis of the experimental data has been carried out by Prof. Manly and his collaborators at RHIC in Brookhaven, NY [C8]. The surprise was that the hydrodynamical flow for non-head-on collisions did not possess the expected longitudinal boost invariance.

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

1. The quantum criticality of the TGD inspired very early cosmology predicts the flatness of 3-space as do also inflationary cosmologies. The TGD inspired cosmology is "silent whisper amplified to big bang" since the matter gradually topologically condenses from decaying cosmic string to the space-time sheet representing the cosmology. This suggests that one could model also the evolution of the quark-gluon plasma in an analogous manner. Now the matter condensing to the quark-gluon plasma space-time sheet would flow from other space-time sheets. The evolution of the quark-gluon plasma would very literally look like the very early critical cosmology.

2. What is so remarkable is that critical cosmology is not a small perturbation of the empty cosmology represented by the future light cone. By perturbing this cosmology so that the spherical symmetry is broken, it might possible to understand qualitatively the findings of [C8]. Maybe even the breaking of the spherical symmetry in the collision might be understood as a strong gravitational effect on distances transforming the spherical shape of the plasma ball to a non–spherical shape without affecting the spherical shape of its M^4_+ projection.

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

4. This picture was completed a couple of years later by the progress made in hadronic mass calculations [K23]. It has already earlier been clear that quarks are responsible only for a small part of the mass of baryons (170 GeV in case of nucleons). The assumption that hadronic $k = 107$ space-time sheet carries a many-particle state of super-symplectic particles with vanishing electro-weak quantum numbers (meaning darkness in the strongest sense of the word.)

5. TGD allows a model of hadrons predicting their masses with accuracy better than one per cent. In this framework color glass condensate can be identified as a state formed when the hadronic space-time sheets of colliding hadrons fuse to single long stringy object and collision energy is transformed to super-symplectic hadrons.

What I have written above reflects the situation around 2005 when RHIC was in blogs. After 5 years later (2010) LHC gave its first results suggesting similar phenomena in proton-proton collisions. These results provide support for the idea that the formation of long entangled hadronic strings by a fusion of hadronic strings forming a structure analogous to black hole or initial string dominated phase of the cosmology are responsible for the RHIC findings. In the LHC case the mechanism leading to this kind of strings must be different since initial state contains only two protons. I would not anymore distinguish between hadrons and super-symplectic hadrons since in the recent picture super-symplectic excitations are responsible for most of the mass of the hadron. The view about dark matter as macroscopic quantum phase with large Planck constant has also evolved a lot from what it was at that time and I have polished reference to some short lived ideas for the benefit of the reader and me. I did not speak about zero energy ontology at that time and the understanding of the general mathematical structure of TGD has improved dramatically during these years.

3.1 Experimental Arrangement And Findings

3.1.1 Heuristic description of the findings

In the experiments using PHOBOS detector ultrahigh energy Au+Au collisions at center of mass energy for which nucleon-nucleon center of mass energy is $\sqrt{s_{NN}} = 130$ GeV, were studied [C7].

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

2. The particles in quark-gluon plasma can be compared to a persons in a crowded room trying to get out. The particles collide many times with the particles of the quark gluon plasma before reaching the surface of the plasma. The distance $d(z,\phi)$ from the point $(z,0)$ at the beam axis to the point $(0,\phi)$ at the plasma surface depends on ϕ. Obviously, the distance is longest to the tips $\phi = \pm\pi/2$ and shortest to the points $\phi = 0, \phi = \phi$ of the surface at the sides of the collision region. The time $\tau(z,\phi)$ spent by a particle to the travel to the plasma surface should be a monotonically increasing function $f(d)$ of d:

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

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

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

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

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

3.1.2 A more detailed description

Consider now the situation in a more quantitative manner.

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

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

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

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

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

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

The hydrodynamical view about the situation looks like follows.

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

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

$$\frac{dN}{d\phi} \simeq 1 + \sum_n v_n cos(n(\phi - \psi_2)) \tag{3.1}$$

   was analyzed in [C8].

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

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

3.2 TGD Based Model For The Quark-Gluon Plasma

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

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

2. The M^4_+ projection of a Robertson-Walker cosmology imbedded to $H = M^4_+ \times CP_2$ is future light cone. Hence it is natural to model the hydrodynamical flow as a mini-cosmology. Even more, one can assume that the collision quite literally creates a space-time sheet which locally obeys Robertson-Walker type cosmology. This assumption is sensible in many-sheeted space-time (see **Fig.** `http://tgdtheory.fi/appfigures/manysheeted.jpg` or **Fig.** 9 in the appendix of this book) and conforms with the fractality of TGD inspired cosmology (cosmologies inside cosmologies).

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

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

3.2.1 The embedding of the critical cosmology

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

$$ds^2 = f(a)da^2 - a^2(K(r)dr^2 + r^2 d\Omega^2) \ . \tag{3.2}$$

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

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

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

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

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

$$\begin{aligned} sin(\Theta) &= \frac{a}{a_m} \ , \\ \Phi &= g(r) \ . \end{aligned} \tag{3.3}$$

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

$$\begin{aligned} f(a) &= 1 - \frac{R^2k^2}{(1-(a/a_m)^2)} \ , \\ (\partial_r\Phi)^2 &= \frac{a_m^2}{R^2} \times \frac{r^2}{1+r^2} \ . \end{aligned} \tag{3.4}$$

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

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

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

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

$$sin^2(\Theta) = (\frac{a}{a_m})^2 \times (1+\Delta(a,\theta,\phi)^2) \ . \tag{3.5}$$

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

$$g_{rr} = -a^2\left[1+\Delta^2(a,\theta,\phi)\frac{r^2}{1+r^2}\right] \ . \tag{3.6}$$

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

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

$$\frac{1}{1-(a/a_m)^2(1+\Delta^2)} \ , \tag{3.7}$$

   which diverges for

$$a_m(\theta,\phi) = \frac{a_m}{\sqrt{1+\Delta^2}} \ . \tag{3.8}$$

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

3.3 Further Experimental Findings And Theoretical Ideas

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

3.3.1 Super-symplectic matter as the TGD counterpart of CGC?

The model discussed above explained the strange breaking of longitudinal Lorentz invariance in terms of a hadronic mini bang cosmology. The next twist in the story was the shocking finding, compared to Columbus's discovery of America, was that, rather than behaving as a dilute gas, the plasma behaved like a liquid with strong correlations between partons, and having density 30-50 times higher than predicted by QCD calculations [C5]. When I learned about these findings towards the end of 2004, I proposed how TGD might explain them in terms of what I called conformal confinement [K19]. This idea - although not wrong for any obvious reason - did not however have any obvious implications. After the progress made in p-adic mass calculations of hadrons leading to highly successful model for both hadron and meson masses [K23], the idea was replaced with the hypothesis that the condensate in question is Bose-Einstein condensate like state of super-symplectic particles formed when the hadronic space-time sheets of colliding nucleons fuse together to form a long string like object.

A further refinement of the idea comes from the hypothesis that quark gluon plasma is formed by the topological condensation of quarks to hadronic strings identified as color flux tubes. This would explain the high density of the plasma. The highly entangled hadronic string would be analogous to the initial state of TGD inspired cosmology with the only difference that string tension is extremely small in the hadronic context. This structure would possess also characteristics of blackhole.

3.3.2 Fireballs behaving like black hole like objects

The latest discovery in RHIC is that fireball, which lasts a mere 10^{-23} seconds, can be detected because it absorbs jets of particles produced by the collision [C6]. The association with the notion black hole is unavoidable and there indeed exists a rather esoteric M-theory inspired model "The RHIC fireball as a dual black hole" by Hortiu Nastase [C11] for the strange findings.

The Physics Today article [C12] "What Have We Learned From the Relativistic Heavy Ion Collider?" gives a nice account about experimental findings. Extremely high collision energies are in question: Gold nuclei contain energy of about 100 GeV per nucleon: 100 times proton mass. The expectation was that a large volume of thermalized Quark-Gluon Plasma (QCP) is formed in which partons lose rapidly their transverse momentum. The great surprise was the suppression of high transverse momentum collisions suggesting that in this phase strong collective interactions are present. This has inspired the proposal that quark gluon plasma is preceded by liquid like phase which has been christened as Color Glass Condensate (CGC) thought to contain Bose-Einstein condensate of gluons.

3.3.3 The theoretical ideas relating CGC to gravitational interactions

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

1. Classical gravitation and color confinement

Just some time ago it became clear that strong classical gravitation might play a key role in the understanding of color confinement [K33]. Whether the situation looks confinement or asymptotic freedom would be in the eyes of beholder: this is one example of dualities filling TGD Universe. If one looks the situation at the hadronic space-time sheet or one has asymptotic freedom, particles move essentially like free massless particles. But - and this is absolutely essential- in the induced metric of hadronic space-time sheet. This metric represents classical gravitational field becoming extremely strong near hadronic boundary. From the point of view of outsider, the motion of quarks slows down to rest when they approach hadronic boundary: confinement. The distance to hadron surface is infinite or at least very large since the induced metric becomes singular at the light-like boundary! Also hadronic time ceases to run near the boundary and finite hadronic time corresponds to infinite time of observer. When you look from outside you find that this light-like 3-surface is just static surface like a black hole horizon which is also a light-like 3-surface. This gives confinement.

2. Dark matter in TGD

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

Matter can be however dark in much stronger sense, should I use the word "black" ! The findings suggesting that planetary orbits obey Bohr rules with a gigantic Planck constant [K30] , [E12] would suggest quantum coherence of dark matter even in astrophysical length scales and this raises the fascinating possibility that Planck constant is dynamical so that fine structure constant. Dark matter would correspond to phases with non-standard value of Planck constant. This quantization saves from black hole collapse just as the quantization of hydrogen atom saves from the infrared catastrophe.

The basic criterion for the transition to this phase would be that it occurs when some coupling strength - say fine structure constant multiplied by appropriate charges or gravitational constant multiplied by masses- becomes so large that the perturbation series for scattering amplitudes fails to converge. The phase transition increases Planck constant so that convergence is achieved. The attempts to build a detailed view about what might happen led to a generalization of the embedding space concept by replacing M^4 (or rather the causal diamond) and CP_2 with their singular coverings. During 2010 it turned out that this generalization could be regarded as a conventional manner to describe a situation in which space-time surface becomes analogous to a multi-sheeted Riemann surface. If so, then Planck constant would be replaced by its integer multiple only in effective sense.

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

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

2. The criterion for the transition to dark phase is however much more general and states that the system does its best to stay perturbative by increasing its Planck constant in discrete steps and applies thus also in the case of color interactions and governs the phase transition to the TGD counterpart of non-perturbative QCD. Criterion would be roughly $\alpha_s Q_s^2 > 1$ for two color charges of opposite sign. Hadronic string picture would suggests that the criterion is equivalent to the generalization of the gravitational criterion to its strong gravity analog $nL_p^2M^2 > 1$, where L_p is the p-adic length scale characterizing color magnetic energy density (hadronic string tension) and M is the mass of the color magnetic flux tube and n is a numerical constant. Presumably L_p, $p = M_{107} = 2^{107} - 1$, is the p-adic length scale since Mersenne prime M_{107} labels the space-time sheet at which partons feed their color gauge fluxes. The temperature during this phase could correspond to Hagedorn temperature (for the history and various interpretations of Hagedorn temperature see the CERN Courier article [B8]) for strings and is determined by string tension and would naturally correspond also to the temperature during the critical phase determined by its duration as well as corresponding black-hole temperature. This temperature is expected to be somewhat higher than hadronization temperature found to be about $\simeq 176$ MeV. The density of inertial mass

would be maximal during this phase as also the density of gravitational mass during the critical phase.

Lepto-hadron physics [K35], one of the predictions of TGD, is one instance of a similar situation. In this case electromagnetic interaction strength defined in an analogous manner becomes larger than unity in heavy ion collisions just above the Coulomb wall and leads to the appearance of mysterious states having a natural interpretation in terms of lepto-pion condensate. Lepto-pions are pairs of color octet excitations of electron and positron.

3. Description of collisions using analogy with black holes

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

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

The valence quarks forming structures connected by color bonds would in the first step of the collision separate from their hadronic space-time sheets which fuse together to form color glass condensate. Similar process has been observed experimentally in the collisions demonstrating the experimental reality of Pomeron, a color singlet state having no Regge trajectory [C10] and identifiable as a structure formed by valence quarks connected by color bonds. In the collision it temporarily separates from the hadronic space-time sheet. Later the Pomeron and the new mesonic and baryonic Pomerons created in the collision suffer a topological condensation to the color glass condensate: this process would be analogous to a process in which black hole sucks matter from environment.

Of course, the relationship between mass and radius would be completely different with gravitational constant presumably replacement by the the square of appropriate p-adic length scale presumably of order pion Compton length: this is very natural if TGD counterparts of black-holes are formed by color magnetic flux tubes. This gravitational constant expressible in terms of hadronic string tension of.9 GeV^2 predicted correctly by super-symplectic picture would characterize the strong gravitational interaction assignable to super-symplectic $J = 2$ gravitons. I have long time ago in the context of p-adic mass calculations formulated quantitatively the notion of elementary particle black hole analogy making the notion of elementary particle horizon and generalization of Hawking-Bekenstein law [K25].

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

4. Quantitative comparison with experimental data

Consider now a quantitative comparison of the model with experimental data. The estimated freeze-out temperature of quark gluon plasma is $T_f \simeq 175.76$ MeV [C12, C11], not far from the total contribution of quarks to the mass of nucleon, which is 170 MeV [K23]. Hagedorn temperature identified as black-hole temperature should be higher than this temperature. The experimental estimate for the hadronic Hagedorn temperature from the transversal momentum distribution of baryons is $\simeq 160$ MeV. On the other hand, according to the estimates of hep-ph/0006020 the values of Hagedorn temperatures for mesons and baryons are $T_H(M) = 195$ MeV and $T_H(B) = 141$ MeV respectively.

D-dimensional bosonic string model for hadrons gives for the mesonic Hagedorn temperature the expression [B8]

$$T_H = \frac{\sqrt{6}}{2\pi(D-2)\alpha'} , \tag{3.9}$$

For a string in $D = 4$-dimensional space-time and for the value $\alpha' \sim 1$ GeV^{-2} of Regge slope, this would give $T_H = 195$ MeV, which is slightly larger than the freezing out temperature as it indeed should be, and in an excellent agreement with the experimental value of [B15]. It deserves to be noticed that in the model for fireball as a dual 10-D black-hole the rough estimate for the temperature of color glass condensate becomes too low by a factor 1/8 [C11]. In light of this I would not yet rush to conclude that the fireball is actually a 10-dimensional black hole.

Note that the baryonic Hagedorn temperature is smaller than mesonic one by a factor of about $\sqrt{2}$. According to [B15] this could be qualitatively understood from the fact that the number of degrees of freedom is larger so that the effective value of D in the mesonic formula is larger. $D_{eff} = 6$ would give $T_H = 138$ MeV to be compared with $T_H(B) = 141$ MeV. On the other hand, TGD based model for hadronic masses [K23] assumes that quarks feed their color fluxes to $k = 107$ space-time sheets. For mesons there are two color flux tubes and for baryons three. Using the same logic as in [B15], one would have $D_{eff}(B)/D_{eff}(M) = 3/2$. This predicts $T_H(B) = 159$ MeV to be compared with 160 MeV deduced from the distribution of transversal momenta in p-p collisions.

3.4 Are Ordinary Black-Holes Replaced With Super-Symplectic Black-Holes In TGD Universe?

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

Baryonic super-symplectic black-holes of the ordinary M_{107} hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their M_{89} counterparts would be 512 times higher, about 478 GeV if quark massses scale also by this factor. This need not be the case: if one has $k = 113 \rightarrow 103$ instead of 105 one has 434 GeV mass. “Ionization energy” for Pomeron, the structure formed by valence quarks connected by color bonds separating from the space-time sheet of super-symplectic black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for M_{89} proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

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

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

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

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) , \tag{3.10}$$

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

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

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2 , \quad (3.11)$$

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

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

$$S = \frac{A}{4G} \times \hbar = \pi G M^2 \times \hbar \ . \quad (3.12)$$

For the p-adic variant of the law Planck mass is replaced with CP_2 mass and $klog(2) \simeq log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if k is prime and wormhole throats have M^4 radius given by p-adic length scale $L_k = \sqrt{k}R$ which is exponentially smaller than L_p. For macroscopic super-symplectic black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [K36] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses M and m [K30] reads as

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

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

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \quad v_0 = 1/2 \ . \quad (3.13)$$

The requirement that $\hbar_{gr}$ is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole [K30]. Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

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

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

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

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

3.5 Very Cautious Conclusions

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

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

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

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

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

3. There is also a connection with the dramatic findings suggesting that Planck constant for dark matter has a gigantic value.

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

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

3.6 Five Years Later

The emergence of the first interesting findings from LHC by CMS collaboration [C4, C1] provide new insights to the TGD picture about the phase transition from QCD plasma to hadronic phase and inspired also the updating of the model of RHIC events (mainly elimination of some remnants from the time when the ideas about hierarchy of Planck constants had just born).

3.6.1 Anomalous behavior of quark gluon plasma is observed also in proton proton collisions

In some proton-proton collisions more than hundred particles are produced suggesting a single object from which they are produced. Since the density of matter approaches to that observed in heavy ion collisions for five years ago at RHIC, a formation of quark gluon plasma and its subsequent decay is what one would expect. The observations are not however quite what QCD plasma picture would allow to expect. Of course, already the RHIC results disagreed with what QCD expectations. What is so striking is the evolution of long range correlations between particles in events containing more than 90 particles as the transverse momentum of the particles increases in the range 1-3 GeV (see the excellent description of the correlations by Lubos Motl in his blog [C2]).

One studies correlation function for two particles as a function of two variables. The first variable is the difference $\Delta\phi$ for the emission angles and second is essentially the difference for the velocities described relativistically by the difference $\Delta\eta$ for hyperbolic angles. As the transverse momentum p_T increases the correlation function develops structure. Around origin of $\Delta\eta$ axis a widening plateau develops near $\Delta\phi = 0$. Also a wide ridge with almost constant value as function of $\Delta\eta$ develops near $\Delta\phi = \pi$. The interpretation is that particles tend to move collinearly and or in opposite directions. In the latter case their velocity differences are large since they move in opposite directions so that a long ridge develops in $\Delta\eta$ direction in the graph.

Ideal QCD plasma would predict no correlations between particles and therefore no structures like this. The radiation of particles would be like blackbody radiation with no correlations between photons. The description in terms of string like object proposed also by Lubos Motl on basis of analysis of the graph showing the distributions as an explanation of correlations looks attractive. The decay of a string like structure producing particles at its both ends moving nearly parallel to the string to opposite directions could be in question.

Since the densities of particles approach those at RHIC, I would bet that the explanation (whatever it is!) of the hydrodynamical behavior observed at RHIC for some years ago should apply also now. The introduction of string like objects in this model was natural since in TGD framework even ordinary nuclei are string like objects with nucleons connected by color flux tubes [L1] , [L1]: this predicts a lot of new nuclear physics for which there is evidence. The basic idea was that in the high density hadronic color flux tubes associated with the colliding nucleon connect to form long highly entangled hadronic strings containing quark gluon plasma. The decay of these structures would explain the strange correlations. It must be however emphasized that in the recent case the initial state consists of two protons rather than heavy nuclei so that the long hadronic string could form from the QCD like quark gluon plasma at criticality when long range fluctuations emerge.

The main assumptions of the model for the RHIC events and those observed now deserve to be summarized. Consider first the "macroscopic description".

1. A critical system associated with confinement-deconfinement transition of the quark-gluon plasma formed in the collision and inhibiting long range correlations would be in question.

2. The proposed hydrodynamic space-time description was in terms of a scaled variant of what I call critical cosmology defining a universal space-time correlate for criticality: the specific property of this cosmology is that the mass contained by comoving volume approaches to zero at the initial moment so that Big Bang begins as a silent whisper and is not so scaring. Criticality means flat 3-space instead of Lobatchevski space and means breaking of

Lorentz invariance to SO(4). Breaking of Lorentz invariance was indeed observed for particle distributions but now I am not so sure whether it has much to do with this.

3. The system behaves like almost perfect fluid in the sense that the viscosity entropy ratio is near to its lower bound whose values is predicted by string theory considerations to be $\eta/s = \hbar/4\pi$.

The microscopic level the description would be like follows.

1. A highly entangled long hadronic string like object (color-magnetic flux tube) would be formed at high density of nucleons via the fusion of ordinary hadronic color-magnetic flux tubes to much longer one and containing quark gluon plasma. In QCD world plasma would not be at flux tube.
2. This geometrically (and perhaps also quantally!) entangled string like object would straighten and split to hadrons in the subsequent "cosmological evolution" and yield large numbers of almost collinear particles. The initial situation should be apart from scaling similar as in cosmology where a highly entangled soup of cosmic strings (magnetic flux tubes) precedes the space-time as we understand it. Maybe ordinary cosmology could provide analogy as galaxies arranged to form linear structures?
3. This structure would have also black hole like aspects but in totally different sense as the 10-D hadronic black-hole proposed by Nastase to describe the findings. Note that M-theorists identify black holes as highly entangled strings: in TGD 1-D strings are replaced by 3-D string like objects.

This picture leaves does not yet make the perfect fluid behavior obvious. The following argument relates it to the properties of the preferred extremals of Kähler action.

Almost perfect fluids seems to be abundant in Nature. For instance, QCD plasma was originally thought to behave like gas and therefore have a rather high viscosity to entropy density ratio $x = \eta/s$. Already RHIC found that it however behaves like almost perfect fluid with x near to the minimum predicted by AdS/CFT. The findings from LHC gave additional conform the discovery [C3]. Also Fermi gas is predicted on basis of experimental observations to have at low temperatures a low viscosity roughly 5-6 times the minimal value [D2] . In the following the argument that the preferred extremals of Kähler action are perfect fluids apart from the symmetry breaking to space-time sheets is developed. The argument requires some basic formulas summarized first.

The detailed definition of the viscous part of the stress energy tensor linear in velocity (oddness in velocity relates directly to second law) can be found in [D1] .

1. The symmetric part of the gradient of velocity gives the viscous part of the stress-energy tensor as a tensor linear in velocity. Velocity gradient decomposes to a term traceless tensor term and a term reducing to scalar.

$$\partial_i v_j + \partial_j v_i = \frac{2}{3}\partial_k v^k g_{ij} + (\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v^k g_{ij}) \ . \tag{3.14}$$

The viscous contribution to stress tensor is given in terms of this decomposition as

$$\sigma_{visc;ij} = \zeta\partial_k v^k g_{ij} + \eta(\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v^k g_{ij}) \ . \tag{3.15}$$

From $dF^i = T^{ij}S_j$ it is clear that bulk viscosity ζ gives to energy momentum tensor a pressure like contribution having interpretation in terms of friction opposing. Shear viscosity η corresponds to the traceless part of the velocity gradient often called just viscosity. This contribution to the stress tensor is non-diagonal and corresponds to momentum transfer in directions not parallel to momentum and makes the flow rotational. This term is essential for the thermal conduction and thermal conductivity vanishes for ideal fluids.

2. The 3-D total stress tensor can be written as

$$\sigma_{ij} = \rho v_i v_j - p g_{ij} + \sigma_{visc;ij} \ . \tag{3.16}$$

The generalization to a 4-D relativistic situation is simple. One just adds terms corresponding to energy density and energy flow to obtain

$$T^{\alpha\beta} = (\rho - p) u^\alpha u^\beta + p g^{\alpha\beta} - \sigma^{\alpha\beta}_{visc} \ . \tag{3.17}$$

Here u^α denotes the local four-velocity satisfying $u^\alpha u_\alpha = 1$. The sign factors relate to the concentrations in the definition of Minkowski metric $((1, -1, -1, -1))$.

3. If the flow is such that the flow parameters associated with the flow lines integrate to a global flow parameter one can identify new time coordinate t as this flow parameter. This means a transition to a coordinate system in which fluid is at rest everywhere (comoving coordinates in cosmology) so that energy momentum tensor reduces to a diagonal term plus viscous term.

$$T^{\alpha\beta} = (\rho - p) g^{tt} \delta^\alpha_t \delta^\beta_t + p g^{\alpha\beta} - \sigma^{\alpha\beta}_{visc} \ . \tag{3.18}$$

In this case the vanishing of the viscous term means that one has perfect fluid in strong sense.

The existence of a global flow parameter means that one has

$$v_i = \Psi \partial_i \Phi \ . \tag{3.19}$$

Ψ and Φ depend on space-time point. The proportionality to a gradient of scalar Φ implies that Φ can be taken as a global time coordinate. If this condition is not satisfied, the perfect fluid property makes sense only locally.

AdS/CFT correspondence allows to deduce a lower limit for the coefficient of shear viscosity as

$$x = \frac{\eta}{s} \geq \frac{\hbar}{4\pi} \ . \tag{3.20}$$

This formula holds true in units in which one has $k_B = 1$ so that temperature has unit of energy.

What makes this interesting from TGD view is that in TGD framework perfect fluid property in appropriately generalized sense indeed characterizes locally the preferred extremals of Kähler action defining space-time surface.

1. Kähler action is Maxwell action with U(1) gauge field replaced with the projection of CP_2 Kähler form so that the four CP_2 coordinates become the dynamical variables at QFT limit. This means enormous reduction in the number of degrees of freedom as compared to the ordinary unifications. The field equations for Kähler action define the dynamics of space-time surfaces and this dynamics reduces to conservation laws for the currents assignable to isometries. This means that the system has a hydrodynamic interpretation. This is a considerable difference to ordinary Maxwell equations. Notice however that the "topological" half of Maxwell's equations (Faraday's induction law and the statement that no non-topological magnetic are possible) is satisfied.

2. Even more, the resulting hydrodynamical system allows an interpretation in terms of a perfect fluid. The general ansatz for the preferred extremals of field equations assumes that various conserved currents are proportional to a vector field characterized by so called Beltrami property. The coefficient of proportionality depends on space-time point and the conserved current in question. Beltrami fields by definition is a vector field such that the time parameters

assignable to its flow lines integrate to single global coordinate. This is highly non-trivial and one of the implications is almost topological QFT property due to the fact that Kähler action reduces to a boundary term assignable to wormhole throats which are light-like 3-surfaces at the boundaries of regions of space-time with Euclidian and Minkowskian signatures. The Euclidian regions (or wormhole throats, depends on one's tastes) define what I identify as generalized Feynman diagrams.

Beltrami property means that if the time coordinate for a space-time sheet is chosen to be this global flow parameter, all conserved currents have only time component. In TGD framework energy momentum tensor is replaced with a collection of conserved currents assignable to various isometries and the analog of energy momentum tensor complex constructed in this manner has no counterparts of non-diagonal components. Hence the preferred extremals allow an interpretation in terms of perfect fluid without any viscosity.

This argument justifies the expectation that TGD Universe is characterized by the presence of low-viscosity fluids. Real fluids of course have a non-vanishing albeit small value of x. What causes the failure of the exact perfect fluid property?

1. Many-sheetedness of the space-time is the underlying reason. Space-time surface decomposes into finite-sized space-time sheets containing topologically condensed smaller space-time sheets containing.... Only within given sheet perfect fluid property holds true and fails at wormhole contacts and because the sheet has a finite size. As a consequence, the global flow parameter exists only in given length and time scale. At embedding space level and in zero energy ontology the phrasing of the same would be in terms of hierarchy of causal diamonds (CDs).

2. The so called eddy viscosity is caused by eddies (vortices) of the flow. The space-time sheets glued to a larger one are indeed analogous to eddies so that the reduction of viscosity to eddy viscosity could make sense quite generally. Also the phase slippage phenomenon of super-conductivity meaning that the total phase increment of the super-conducting order parameter is reduced by a multiple of 2π in phase slippage so that the average velocity proportional to the increment of the phase along the channel divided by the length of the channel is reduced by a quantized amount.

   The standard arrangement for measuring viscosity involves a lipid layer flowing along plane. The velocity of flow with respect to the surface increases from $v = 0$ at the lower boundary to v_{upper} at the upper boundary of the layer: this situation can be regarded as outcome of the dissipation process and prevails as long as energy is fed into the system. The reduction of the velocity in direction orthogonal to the layer means that the flow becomes rotational during dissipation leading to this stationary situation.

   This suggests that the elementary building block of dissipation process corresponds to a generation of vortex identifiable as cylindrical space-time sheets parallel to the plane of the flow and orthogonal to the velocity of flow and carrying quantized angular momentum. One expects that vortices have a spectrum labelled by quantum numbers like energy and angular momentum so that dissipation takes in discrete steps by the generation of vortices which transfer the energy and angular momentum to environment and in this manner generate the velocity gradient.

3. The quantization of the parameter x is suggestive in this framework. If entropy density and viscosity are both proportional to the density n of the eddies, the value of x would equal to the ratio of the quanta of entropy and kinematic viscosity η/n for single eddy if all eddies are identical. The quantum would be $\hbar/4\pi$ in the units used and the suggestive interpretation is in terms of the quantization of angular momentum. One of course expects a spectrum of eddies so that this simple prediction should hold true only at temperatures for which the excitation energies of vortices are above the thermal energy. The increase of the temperature would suggest that gradually more and more vortices come into play and that the ratio increases in a stepwise manner bringing in mind quantum Hall effect. In TGD Universe the value of h_{eff} can be large in some situations so that the quantal character of dissipation could become visible even macroscopically. Whether this a situation with large h_{eff} is encountered even in the case of QCD plasma is an interesting question.

The following poor man's argument tries to make the idea about quantization a little bit more concrete.

1. The vortices transfer momentum parallel to the plane from the flow. Therefore they must have momentum parallel to the flow given by the total cm momentum of the vortex. Before continuing some notations are needed. Let the densities of vortices and absorbed vortices be n and n_{abs} respectively. Denote by $v_{\parallel}$ *resp.* $v_{\perp}$ the components of cm momenta parallel to the main flow *resp.* perpendicular to the plane boundary plane. Let m be the mass of the vortex. Denote by S are parallel to the boundary plane.

2. The flow of momentum component parallel to the main flow due to the absorbed at S is

$$n_{abs} m v_{\parallel} v_{\perp} S \quad . \tag{3.21}$$

   This momentum flow must be equal to the viscous force

$$F_{visc} = \eta \frac{v_{\parallel}}{d} \times S \quad . \tag{3.22}$$

   From this one obtains

$$\eta = n_{abs} m v_{\perp} d \quad . \tag{3.23}$$

   If the entropy density is due to the vortices, it equals apart from possible numerical factors to

$$s = n$$

   so that one has

$$\frac{\eta}{s} = m v_{\perp} d \quad . \tag{3.24}$$

   This quantity should have lower bound $x = \hbar/4\pi$ and perhaps even quantized in multiples of x, Angular momentum quantization suggests strongly itself as origin of the quantization.

3. Local momentum conservation requires that the comoving vortices are created in pairs with opposite momenta and thus propagating with opposite velocities $v_{\perp}$. Only one half of vortices is absorbed so that one has $n_{abs} = n/2$. Vortex has quantized angular momentum associated with its internal rotation. Angular momentum is generated to the flow since the vortices flowing downwards are absorbed at the boundary surface.

   Suppose that the distance of their center of mass lines parallel to plane is $D = \epsilon d$, ϵ a numerical constant not too far from unity. The vortices of the pair moving in opposite direction have same angular momentum $mv \ D/2$ relative to their center of mass line between them. Angular momentum conservation requires that the sum these relative angular momenta cancels the sum of the angular momenta associated with the vortices themselves. Quantization for the total angular momentum for the pair of vortices gives

$$\frac{\eta}{s} = \frac{n\hbar}{\epsilon} \tag{3.25}$$

Quantization condition would give

$$\epsilon = 4\pi \ . \tag{3.26}$$

One should understand why $D = 4\pi d$ - four times the circumference for the largest circle contained by the boundary layer- should define the minimal distance between the vortices of the pair. This distance is larger than the distance d for maximally sized vortices of radius $d/2$ just touching. This distance obviously increases as the thickness of the boundary layer increases suggesting that also the radius of the vortices scales like d.

4. One cannot of course take this detailed model too literally. What is however remarkable that quantization of angular momentum and dissipation mechanism based on vortices identified as space-time sheets indeed could explain why the lower bound for the ratio η/s is so small.

4 Some Problems Of Cosmology

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

4.1 Antimatter as dark matter in TGD sense?

One possibility is that antimatter corresponds to dark matter in TGD sense: that is a phase with non-standard value of Planck constant. It has been found in CERN (seehttp://tinyurl.com/jbvwmrp3) that matter and antimatter atoms have no differences in the energies of their excited states. This is predicted by CPT symmetry. Notice however that CP and T can be separately broken and that this is indeed the case. Kaon is classical example of this in particle physics. Neutral kaon and anti-kaon behave slightly differently.

This finding forces to repeat an old question. Where does the antimatter reside? Or does it exist at all?

In TGD framework one possibility is that antimatter corresponds to dark matter in TGD sense that is a phase with $h_{eff} = n \times h$, $n = 1, 2, 3, ...$ such that the value of n for antimatter is different from that for visible matter. Matter and antimatter would not have direct interactions and would interact only via classical fields or by emission of say photons by matter (antimatter) suffering a phase transition changing the value of h_{eff} before absorbtion by antimatter (matter). This could be rather rare process. Bio-photons could be produced from dark photons by this process and this is assumed in TGD based model of living matter.

What the value of n for ordinary visible matter is? The naïve guess is that it is $n = 1$, the smallest possible value. Randell Mills [D3] has however claimed the existence of scaled down hydrogen atoms - Mills calls them hydrinos - with ground state binding energy considerably higher than for hydrogen atom. The experimental support for the claim is published in respected journals and the company of Mills is developing a new energy technology based on the energy liberated in the transition to hydrino state (see http://tinyurl.com/hajyqo6).

These findings can be understood in TGD framework if one has actually $n = 6$ for visible atoms and $n = 1, 2$, or 3 for hydrinos. Hydrino states would be stabilized in the presence of some catalysts (see http://tinyurl.com/goruuzm) [L11]. This also suggests a universal catalyst action. Among other things catalyst action requires that reacting molecule gets energy to overcome the potential barrier making reaction very slow. If an atom - say hydrogen - in catalyst suffers a phase transition to hydrogen like state, it liberates binding energy, and if one of the reactant molecules receives it it can overcome the barrier. After the reaction the energy can be sent back and catalyst hydrino returns to the ordinary hydrogen state.

So: could it be that one has n=6 for stable matter and n is different from this for stable antimatter? Could the small CP breaking cause this?

4.2 Why Some Stars Seem To Be Older Than The Universe?

There exists experimental evidence that some stars are older than the Universe [E22], [E27, E22]. A related problem is the problem of the two Hubble constants. These paradoxical results can be understood in TGD inspired cosmology. In TGD light can propagate via several routes. In the topological condensate light ray can propagate along one of the many curved space-time sheet as a small condensed particle and in the vapor phase as a small 3-surface in embedding space $H = M^4_+ \times CP_2$, where M^4_+ is future light cone of M^4. The time needed to travel from point A to point B is shorter in the vapor phase than in any space-time surface since the geodesic length along the space-time surface in the induced metric is obviously longer than in free Minkowski space. This time depends also on the space-time sheet so that entire spectrum of effective light velocities and Hubble constants results. The failure to distinguish between vapor phase photons and photons propagating along various space-time sheets leads to the paradox as following arguments shows and possibly also to the problem of two (or in fact more than two) different Hubble constants. The possibility of the vapor phase photons or photons propagating along almost flat space-time sheets emitted by the objects outside the space-time horizon of "our" space-time sheet explains also objects with anomalously large red shifts.

4.2.1 Basic facts

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

1. The most general cosmological embedding of M^4_+ to $M^4_+ \times \mathrm{CP}_2$ $, is of form$

$$\begin{aligned} s^k &= s^k(a) \ , \\ g_{aa} &= 1 - s_{kl}\frac{ds^k}{da}\frac{ds^l}{da} \ , \\ ds^2 &= g_{aa}da^2 - a^2\left(\frac{dr^2}{1+r^2} + r^2 d\Omega^2\right) \ . \end{aligned} \tag{4.1}$$

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

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

$$\frac{age(cond)}{age(vapor)} = \frac{s(a)}{a} = \frac{2}{3}\sqrt{g_{aa}} \ , \tag{4.2}$$

for the ratio of the ages.

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

$$\begin{aligned} \rho &= \frac{3}{8\pi G}\left(\frac{1}{g_{aa}} + k\right) \ , \\ k &= -1 \ . \end{aligned} \tag{4.3}$$

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

$$\begin{aligned} \sqrt{g_{aa}} &= \sqrt{1-\epsilon} \ , \\ \epsilon &= \frac{\rho}{\rho_c} \ . \end{aligned} \tag{4.4}$$

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

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

$$\frac{\tau(cond)}{\tau(vapor)} = \frac{1}{\sqrt{g_{aa}}} \quad . \tag{4.5}$$

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

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

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

$$\begin{aligned} r &= sinh(X) \ , && \text{(hyperbolic cosmology)} \ , \\ r &= X \ , && \text{(critical cosmology)} \ , \\ X &= \textstyle\int_{a_0}^{a} \frac{\sqrt{g_{aa}}}{a} da \ . && \end{aligned} \tag{4.6}$$

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

4.2.2 Maximum Minkowski distance from which light can propagate

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

$$\begin{aligned} \sqrt{g_{aa}} &= tanh(X) \ , \ \text{(hyperbolic cosmology)} \ , \\ \sqrt{g_{aa}} &= X \ , \ \text{(critical cosmology)} \ . \end{aligned} \tag{4.7}$$

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

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

$$u_0 = tanh(2(u - u_0)) \simeq 2(u - u_0) \ , \quad u = \sqrt{Ka} \ , \quad u_0 = \sqrt{Ka_0} \ . \tag{4.8}$$

This gives in good approximation

$$u_0 = r = \tfrac{2}{3}u \ , \quad a_0 = \tfrac{4}{9}a \ , \quad r_M^0 = \tfrac{8}{27}ua = \tfrac{16}{81}\sqrt{Ka} \times a \ . \tag{4.9}$$

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

$$r_M^0 = a \ . \tag{4.10}$$

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

$$a_0 = \frac{a}{e} \ , \quad r_0 = 1 \ , \quad r_M^0 = \frac{a}{e} \ . \tag{4.11}$$

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

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

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

$$\frac{a}{a_1} = exp(2\sqrt{K_1}(a^{1/2} - a_0^{1/2})) \ . \tag{4.12}$$

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

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

Red-shifts are determined by the apparent velocity of astrophysical object which is in good approximation given $v = Hr$, where H is Hubble constant which in TGD depends on space-time sheet along which photons propagate. One has $r = sinh(X)$ for hyperbolic cosmology and $r = X$ for critical cosmology, where the function X is defined by Eq. 4.6. For matter dominated cosmology with $g_{aa} = Ka$ and for almost flat hyperbolic cosmology with $g_{aa} = 1 - \epsilon$ one has

$$\begin{aligned} X &= 2\left[(Ka)^{1/2} - (Ka_0)^{1/2}\right] < 1 \ , && \text{(matter dominance)} \ , \\ X &= \sqrt{(1-\epsilon)}log(\tfrac{a}{a_0}) \ , && \text{(almost flat hyperbolic)} \ . \end{aligned} \tag{4.13}$$

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

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

4.2.5 The puzzle of several Hubble constants

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

$$H = \frac{1}{a\sqrt{g_{aa}}} , \tag{4.14}$$

where the value of the light cone proper time corresponds to the light cone proper time of observer in the sub-light cone defined by the sub-cosmology. The value of Hubble constant is smallest at almost flat space-time sheets. Photons propagating along almost flat space-time sheet or in vapor phase provide a possible solution to the puzzle of two different Hubble constants if the mass density is sufficiently large. The distances derived from type Ia super-novae give $H_0^a = 54 \pm 8\ kms^{-1}Mpc^{-1}$ to be compared with the Hubble result $H_0^b = 80 \pm 17\ kms^{-1}Mpc^{-1}$ [E22], [E22].

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

$$\frac{H_0^a}{H_0^b} = \frac{H_0(M_+^4)}{H_0(X^4)} = \sqrt{g_{aa}} = \sqrt{1-\epsilon} \sim 2/3 \tag{4.15}$$

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

For instance, for the space-time outside the Kähler charged cosmic string, discussed in [K7], one has

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

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

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

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

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

1. The problem of two Hubble constants persists

The previous comments about the problem of two Hubble constants was written as one of the first applications of TGD inspired cosmology and the problem might have disappeared with improved measurement technology. After about two decades the problem is however still here.

The rate of cosmic expansion manifesting itself as cosmic redshift is proportional to the distance r of the object: the expansion velocity satisfies in good approximation $v = Hr$. The proportionality coefficients H is known as Hubble constant. Hubble constant has dimensions of 1/s. A more convenient parameter is Hubble length defined as $L_H = c/H$, whose nominal value is 14.4 light years and corresponds to the limit at which the distant object recedes with light velocity from observer.

1. The measurement of Hubble constant requires determination of distance of astrophysical object (see `http://tinyurl.com/qe8rqh6`). For instance, the distance using so called standard candles - type I a supernovae having always same brightness decreasing like inverse square of distance (cosmic redshift also reduces the total intensity by shifting the frequencies). This method works for not too large distances (few hunder million light years, the size scale of the large voids (see `http://tinyurl.com/gug9264`)): therefore this method gives the value of the local Hubble constant.

2. The rate can be also deduced from cosmic redhift for CMB radiation. This method gives the Hubble constant in cosmic scales considerably longer than the size of large voids: one speaks of global determination of Hubble constant.

The problem has been that local and global method give different values for H. One might hope that the discrepancy should disappear as measurements become more precise. The recent determinination of the local value of the Hubble constant however demonstrates that the problem persists [E29] (see `http://tinyurl.com/hlr7gah`). The global value is roughly 9 per cent smaller than the local value. For a popular articles about the finding see `http://tinyurl.com/zrxay8j`).

The explanation of the discrepancy [K31] in terms of many-sheeted space-time was one of the first applications of TGD inspired cosmology. The local value of Hubble constant would correspond to space-time sheets of size at most that of large void. Global value would correspond to space-time sheets with size scales up to ten billion years assignable to the entire observed cosmos. The smaller value of the Hubble constant for space-time sheets of cosmic size would reflect the fact that the metric for them corresponds to a smaller average density for them. Mass density would be fractal in accordance with the fractality of TGD Universe implied by many-sheetedness.

Reader has perhaps noticed that I have been talking about space-time sheets in plural. The space-time of TGD is indeed many-sheeted 4-D surface in 8-D $M^4 \times CP_2$. It corresponds approximately to GRT space-time in the sense that the gauge potentials and gravitational fields (deviation of induced metric from Minkowksi metric) for sheets sum up to the gauge potential and gravitational field for the space-time of GRT characterized by metric and gauge potentials in standard model. Many-sheetedness leads to predictions allowing to distinguish between GRT and TGD. For instance, the propagation velocities of particles along different space-time sheets can differ since the light-velocity along space-time sheets is typically smaller than the maximal signal velocity in empty Minkowski space M^4. Evidence for this effect has been observed [K1]. For the first time for supernova 1987A: neutrinos arrived in two bursts and also gamma ray burst arrived at different time than neutrinos: as if the propagation would have taken place along different space-time sheets. Second time for the neutrinos arriving from galactic blackhole Sagittarius A. Two pulses were detected and the difference for arrival time was few hours.

2. Solution of Hubble constant discrepancy from the length scale dependence of cosmological constant

The discrepancy of the two determinations of Hubble constant has led to a suggestion that new physics might be involved (see `http://tinyurl.com/yabszzeg`).

1. Planck observatory deduces Hubble constant H giving the expansion rate of the Universe from CMB data something like 360,000 y after Big Bang, that is from the properties of

the cosmos in long length scales. Riess's team deduces H from data in short length scales by starting from galactic length scale and identifies standard candles (Cepheid variables), and uses these to deduce a distance ladder, and deduces the recent value of $H(t)$ from the redshifts.

2. The result from short length scales is 73.5 km/s/Mpc and from long scales 67.0 km/s/Mpc deduced from CMB data. In short length scales the Universe appears to expand faster. These results differ too much from each other. Note that the ratio of the values is about 1.1. There is only 10 percent discrepancy but this leads to conjecture about new physics: cosmology has become rather precise science!

TGD could provide this new physics. I have already earlier considered this problem but have not found really satisfactory understanding. The following represents a new attempt in this respect.

1. The notions of length scale are fractality are central in TGD inspired cosmology. Many-sheeted space-time forces to consider space-time always in some length scale and p-adic length scale defined the length scale hierarchy closely related to the hierarchy of Planck constants $h_{eff}/h_0 = n$ related to dark matter in TGD sense. The parameters such as Hubble constant depend on length scale and its value differ because the measurements are carried out in different length scales.

2. The new physics should relate to some deep problem of the recent day cosmology. Cosmological constant Λ certainly fits the bill. By theoretical arguments Λ should be huge making even impossible to speak about recent day cosmology. In the recent day cosmology Λ is incredibly small.

3. TGD predicts a hierarchy of space-time sheets characterized by p-adic length scales (Lk) so that cosmological constant Λ depends on p-adic length scale $L(k)$ as $\Lambda \propto 1/GL(k)^2$, where $p \simeq 2^k$ is p-adic prime characterizing the size scale of the space-time sheet defining the sub-cosmology. p-Adic length scale evolution of Universe involve as sequence of phase transitions increasing the value of $L(k)$. Long scales $L(k)$ correspond to much smaller value of Λ.

4. The vacuum energy contribution to mass density proportional to Λ goes like $1/L^2(k)$ being roughly $1/a^2$, where a is the light-cone proper time defining the "radius" $a = R(t)$ of the Universe in the Robertson-Walker metric $ds^2 = dt^2 - R^2(t)d\Omega^2$. As a consequence, at long length scales the contribution of Λ to the mass density decreases rather rapidly.

   Must however compare this contribution to the density ρ of ordinary matter. During radiation dominated phase it goes like $1/a^4$ from $T \propto 1/a$ and form small values of a radiation dominates over vacuum energy. During matter dominated phase one has $\rho \propto 1/a^3$ and also now matter dominates. During predicted cosmic string dominated asymptotic phase one has $\rho \propto 1/a^2$ and vacuum energy density gives a contribution which is due to Kähler magnetic energy and could be comparable and even larger than the dark energy due to the volume term in action.

5. The mass density is sum $\rho_m + \rho_d$ of the densities of matter and dark energy. One has $\rho_m \propto H^2$. $\Lambda \propto 1/L^2(k)$ implies that the contribution of dark energy in long length scales is considerably smaller than in the recent cosmology. In the Planck determination of H it is however assumed that cosmological constant is indeed constant. The value of H in long length scales is under-estimated so that also the standard model extrapolation from long to short length scales gives too low value of H. This is what the discrepancy of determinations of H performed in two different length scales indeed demonstrate.

A couple of remarks are in order.

1. The twistor lift of TGD [K34, L10] [L19] suggests an alternative parameterization of vacuum energy density as $\rho_{vac} = 1/L^4(k_1)$. k_1 is roughly square root of k. This gives rise to a pair of short and long p-adic length scales. The order of magnitude for $1/L(k_1)$ is roughly the same as that of CMB temperature T: $1/L(k_1) \sim T$. Clearly, the parameters $1/T$ and R correspond to a pair of p-adic length scales. The fraction of dark energy density becomes smaller during

the cosmic evolution identified as length scale evolution with largest scales corresponding to earliest times. During matter dominated era the mass density going like $1/a^3$ would to dominate over dark energy for small enough values of a. The asymptotic cosmology should be cosmic string dominated predicting $1/GT^2(k)$. This does not lead to contradiction since Kähler magnetic contribution rather than that due to cosmological constant dominates.

2. There are two kinds of cosmic strings: for the other type only volume action is non-vanishing and for the second type both Kähler and volume action are non-vanishing but the contribution of the volume action decreases as function of the length scale.

4.2.6 Cosmic redshift but no expansion of receding objects: one further piece of evidence for TGD cosmology

"Universe is Not Expanding After All, Controversial Study Suggests" was the title of very interesting Science News article (see `http://tinyurl.com/o6vyb9g`) telling about study, which forces to challenge Big Bang cosmology. The title of course involved the typical exaggeration.

The idea behind the study was simple. If Universe expands and also astrophysical objects - such as stars and galaxies - participate the expansion, they should increase in size. The observation was that this does not happen! One however observes the cosmic redshift so that it is too early to start to bury Big Bang cosmology. This finding is however a strong objection against the strongest version of expanding Universe. That objects like stars do not participate the expansion was actually known already when I developed TGD inspired cosmology for quarter century ago, and the question is whether GRT based cosmology can model this fact naturally or not.

The finding supports TGD cosmology based on many-sheeted space-time. Individual space-time sheets do not expand continuously. They can however expand in jerk-wise manner via quantum phase transitions increasing the p-adic prime characterizing space-time sheet of object by say factor two of increasing the value of $h_{eff} = n \times h$ for it. This phase transition could change the properties of the object dramatically. If the object and suddenly expanded variant of it are not regarded as states of the same object, one would conclude that astrophysical objects do not expand but only comove. The sudden expansions should be observable and happen also for Eart. I have proposed a TGD variant of Expanding Earth hypothesis along these lines [L18].

When one approximates the many-sheeted space-time of TGD with GRT space-time, one compresses the sheets to single region of slightly curved piece of M^4 and gauge potentials and the deviation of induced metric from M^4 metric are replaced with their sums over the sheets to get standard model. This operation leads to a loss of information about many-sheetedness. Many-sheetedness demonstrates its presence only through anomalies such as different value of Hubble constant in scales of order large void and cosmological scales, arrival of neutrinos and gamma rays from supernova SN1987A as separate bursts (arrival through different space-time sheets). The above observation represents one such anomaly.

One can of course argue that cosmic redshift is a strong counter argument against TGD. Conservation of energy and momentum implied by Poincare invariance at the level of embedding space $M^4 \times CP_2$ does not seem to allow cosmic redshift. This is not the case. Photons arrive from the source without losing their energy. The point is that the source and observer are different gravitationally. The local gravitational field defined by the induced metric induces Lorentz boost of the M^4 projection of the tangent space of the space-time surface so that the tangent spaces at source and receiver are boosted with respect to other: this causes the gravitational redshift as analog of Doppler effect in special relativity.

The TGD inspired prediction would be that the radii of the observed rings are integer multiples of basic radius. 4 rings are reported implying that the outermost ring should be at distance of 240,000 ly, which is considerably larger than the claimed updated size of 150,000 ly. The simple quantization as integer multiples would not be quite correct. Orders of magnitude are however correct.

This would suggest that visible matter has condensed around dark matter at Bohr quantized orbits or circular flux tubes. This dark matter would contribute to the gravitational potential and imply that the velocity spectrum for distance stars is not quite constant but increases slowly as observed (see `http://tinyurl.com/hqzzpfs`).

4.3 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. These phase transitions might be initiated by the repulsive Coulomb interaction between cosmic strings driven to the boundaries of the large voids. It is interesting to see how this view relates with the assumption of positive cosmological constant.

4.3.1 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

$$\begin{aligned} H^2 &\equiv (\frac{da/ds}{a})^2 = \frac{8\pi G\rho + \Lambda}{3} - K/a^2,\quad K = 0, \pm 1 \ , \\ 3\frac{d^2a/ds^2}{a} &= \Lambda - 4\pi G(\rho + 3p) \equiv -4\pi G(1+3w)\rho \ . \end{aligned} \tag{4.16}$$

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)

$$-G^{\alpha\beta} - \Lambda g^{\alpha\beta} = 8\pi G T^{\alpha\beta} \tag{4.17}$$

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 [E3] the densities of dark energy, ordinary matter, and dark matter are assumed to sum up to critical mass density $\rho_{cr} = 3/(8\pi g_{aa}Ga^2)$. The fraction of dark matter density is deduced to be $\Omega_\Lambda = .74$ from mere criticality.

4.3.2 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

$$3\frac{d^2a/ds^2}{a} = \Lambda - 4\pi G(\rho + 3p) \ . \tag{4.18}$$

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

$$q \equiv -a\frac{d^2a/ds^2}{(da/ds)^2} \ . \tag{4.19}$$

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

$$g_{aa} \equiv (ds/da)^2 = 1 - K_0 \ . \tag{4.20}$$

In this case one has $q = 0$.

2. Critical cosmology

Critical cosmology with flat 3-space corresponds to

$$\begin{aligned} g_{aa} &= 1 - K \ , \\ K &\equiv \frac{K_0}{1-u^2} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{4.21}$$

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

$$q = -K_0 \frac{K_0 u^2}{1-u^2-K_0} < 0 \ , \tag{4.22}$$

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

$$\frac{dH/ds}{H^2} = -(1+q) \ , \tag{4.23}$$

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

$$\begin{aligned} g_{aa} &= \frac{1-2x}{1-x} \ , \\ x &= (\frac{a_0}{a})^{2/3} \ . \end{aligned} \tag{4.24}$$

The deceleration parameter

$$q = \frac{1}{3}\frac{x}{(1-2x)(1-x)} \ . \tag{4.25}$$

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 [K15, K13] and p-adic length scale hypothesis suggests.

4. Summary

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. 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 (EP) in the formulation provided by General Relativity sense fails locally in TGD framework (no failure in stringy sense and at quantum level). The counterpart for EP would be the vanishing of the energy momentum tensor for Kähler action guaranteed by Einstein's equations but not implying them. 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 only effective pressure is negative. TGD description has some resemblance to the description in terms of quintessence [E4], 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.

4.3.3 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 $\Omega_\Lambda \simeq .74$.

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

2. The dark matter hierarchy labeled by the values of Planck constant suggests itself. The $1/a^2$ behavior of dark matter density suggests an interpretation as dark matter topologically condensed on cosmic strings. Besides ordinary particles also super-symplectic bosons and their super partners playing a key role in the model of hadrons and black holes suggest themselves.

3. 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 should 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.

4.3.4 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 and large repulsive Coulomb energy forces the phase transition increasing Planck constant.

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 [E42] 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 [E8], 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.

4.3.5 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 [E7]. If a period of an accelerated expansion has been preceded by a decelerated one, one would naïvely 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 [E28] 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

$$\mathcal{F} = \frac{\mathcal{L}}{4\pi d_L^2} \ , \tag{4.26}$$

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

$$\begin{aligned} d_L &= (1+z)\int_0^z \frac{du}{H(u)} \\ &= (1+z)H_0^{-1}\int_0^z exp\left[-\int_0^u du\,[1+q(u)]\,d(ln(1+u))\right]du \ , \end{aligned} \tag{4.27}$$

where one has

$$\begin{aligned} H(z) &= \frac{dln(a)}{ds} \ , \\ q &\equiv -\frac{d^2a/ds^2}{aH^2} = \frac{dH^{-1}}{ds} - 1 \ . \end{aligned} \tag{4.28}$$

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.

4.4 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.

Neil Turok's recent talk at PASCOS was 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.

4.4.1 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 [E6].

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 [K26].

4.4.2 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 effective Λ it is possible that no transitions reducing effective 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 already 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.

4.5 Could Many-Sheeted Cosmology Explain The Claimed Time Dependence Of The Fine Structure Constant?

There is recent evidence for the time dependence of the fine structure constant in cosmological time scales [E30]. The spectroscopic observations of a number of absorption systems in the spectra of distant quasars indicate a smaller value of α in the past. The comparison of the ratios of the frequencies for relativistic atomic transitions depending non-linearly on α^2 gives the average value $\Delta\alpha/\alpha = -0.72 \pm .18 \times 10^{-5}$ in the red shift range $z = .5 - 3.5$.

On the other hand, the data about the isotopic abundances in Oklo natural reactor which operated at 1.8×10^9 years ago gives the upper bound $\Delta\alpha/\alpha \leq 10^{-7}$ [E9]: this corresponds to the red shift $z = .13$. This suggests an abrupt change of the fine structure constant in the range $.13 < z_0 \leq .5$.

A further important piece of data is about type Ia super-novae in distant galaxies. These data have extended the Hubble diagram to red shifts $z \geq 1$ [E26]. The data imply an accelerated expansion of the universe in the framework of standard cosmology requiring the introduction of cosmological constant and vacuum energy density of unknown origin. More recent measurements have measured no variation [E18]. Despite this it is an interesting exercise to see whether the variation might have some explanation in TGD framework.

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

4.5.1 Classical model based on many-sheeted space-time

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

1. The basic idea is that atomic nuclei need not feed their entire electric gauge fluxes to the atomic space-time sheet, which presumably corresponds to $p \simeq 2^k$, $k = 131$ or $k = 137$, but can feed a small fraction of the electric flux also to the larger space-time sheets. The simplest assumption is that each new cosmological space-time sheet receives a constant fraction of the existing nuclear gauge charge. Stability requirement suggests that also each electron feeds a negative fraction of its electric flux to the larger space-time sheet so that an overall charge neutrality is preserved. The fraction must be negative to guarantee that the nuclear and electronic charges effectively increase in magnitude when new larger space-time sheets emerge during the cosmological evolution. Negative fraction is favored also by the fact that the effective nuclear charge would otherwise approach zero in the sufficiently distant geometric

future. The effect corresponds to an apparent renormalization of the fine structure constant having nothing to do with the ordinary QED renormalization or the renormalization of the fine structure constant suggested by the p-adic coupling constant evolution.

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

3. If the p-adic length scale L_p appears at $t = a \simeq L_p$ then p-adic length scales appear at $a(k_n) = 2^{(k_n-k_0)/2}a_{k_0}$. The effective fine structure constant is predicted to be constant inside intervals $[a(k_n), a(k_{n-1})]$. The minimum value for the increment of k_n is $\Delta k = k_n - k_{n-1} = 2$ and corresponds to a variation of a by single octave and to a pair of twin primes $k_n = k_{n-1}+2$. This predicts the constancy of the effective fine structure constant after $z = z_0$ in accordance with the experimental facts. If $z_0 = a_{now}/a_0 - 1$ corresponds to the first abrupt change in the range $.13 < z_0 < .5$ then for $\Delta k = 2$ another abrupt change would occur at $z_1 = 2z_0 + 1$, $1.26 < z_1 < 3$. If each space-time sheet receives the same amount of electric flux, one has $\Delta[log(\alpha\ )\ ]\ (\mathrm{z}_1) \simeq 2\Delta[log(\alpha)](z_0)$, which is excluded in the range considered. For $\Delta k = 4$ the next abrupt change would correspond to $z_2 = 4z_0 + 3$: $3.52 < z_2 < 5$. Unfortunately, this value of z is slightly above the range studied in [E31]. For $\Delta k = 6$ one would have $z_3 = 8z_0 + 7$, $8 < z_3 < 11$.

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

Note that this model might be seen as a topological and microscopic version of the Bekenstein's field theory model [E34] based on the assumption that fine structure constant is a slowly varying scalar field Φ having naturally the needed linear coupling to the Maxwell action. In [E9] it was suggested that Φ could correspond to the so called quintessence field believed to give rise to cosmological vacuum energy and that Bekenstein's model could explain the observed variation of the fine structure constant. Note that in many-sheeted cosmology charge conservation is not lost although the effective fine structure constant depends on cosmological time.

4.5.2 Could hierarchy of Planck constants be involved?

The introduction of hierarchy of Planck constants [K13, K27] suggests also mechanisms based on charge fractionization and change of Planck constant from its standard value.

Fine structure constant is proportional to $1/\hbar$. In the lowest order perturbative QED the predictions are more or less same as the predictions of classical theory and do not depend at all on $\hbar$. Radiation corrections appear in higher orders in powers of α, and would allow to deduce the value of $\hbar$ associated with the dark matter system. The possibility that the value of $\hbar/\hbar_0$, which is rational number, has changed a little bit in past for what we regard as visible matter does not however look very plausible.

One can imagine also another effect related to the hierarchy of Planck constants.

1. The pages of the book like structures associated with causal diamond CD and CP_2 are labeled by integers n_a and n_b characterizing the cyclic group associated with the singular covering or factor space defining the page. Both n_a and n_b could make themselves visible physical if the

Kähler gauge potential has a pure gauge part ΔA in both CD and CP_2 degrees of freedom (with g_K included as scaling factor so that ΔA has dimension of $\hbar$) [K27]. This would give a fractional shift to both spin and color hyper charge and color isospin.

2. Since the holonomy group of CP_2 identifiable as electro-weak gauge group corresponds in natural manner to the $U(2)$ subgroup of color group, the interpretation of the anomalous color hyper charge and color isospin in terms of anomalous weak isospin and hyper charge can be considered.

3. This contribution to the charge in units of $\hbar_0$ would be of form $(a\Delta A_\psi + b\Delta A_\Phi)/\hbar_0$, where Ψ and Φ denote the phases assignable to the complex coordinates of CP_2 transforming linearly under $U(2)$. For a page of CP_2 book, which corresponds to a singular covering characterized by integer n_b, the physically most plausible scenario would give $\Delta A_\Psi = \Delta A_\Phi = \hbar_0/n_b$ for coverings so that for coverings em charge would be shifted by $1/n_b$ units. For singular factor spaces formal guess would be $\Delta A_\Psi = \Delta A_\Phi = \hbar_0 n_b$. One can argue that ΔA can be eliminated by a global gauge transformation: this transformation however induces a phase into induced spinor field giving rise to anomalous charge. This fractionization means a shift of the charge so that even neutrino would receive a small fractional em charge. Nothing prevents from asking whether this kind of fractionization could actually take place and seeing the trouble of demonstrating that it cannot be involved with the claimed anomaly.

4.5.3 Could cosmos have North-South axis: How?

Wes Johnson told about very interesting observations suggesting that cosmology has North-South (N-S) axis in the sense that fine structure constant has N-S variation with respect to this axis. The popular article is at `http://tinyurl.com/yct36gff`. Here is the abstract of the article of Webb *et al* [E32] (`https://tinyurl.com/ycpo4kcv`).

Observations of the redshift $z = 7.085$ *quasar J1120+0641 are used to search for variations of the fine structure constant, a, over the redshift range 5.5 to 7.1. Observations at* $z = 7.1$ *probe the physics of the universe at only 0.8 billion years old. These are the most distant direct measurements of a to date and the first measurements using a near-IR spectrograph. A new AI analysis method is employed. Four measurements from the X-SHOOTER spectrograph on the Very Large Telescope (VLT) constrain changes in a relative to the terrestrial value* (α_0)*. The weighted mean electromagnetic force in this location in the universe deviates from the terrestrial value by* $\Delta\alpha/\alpha = (\alpha_z - \alpha_0)/\alpha_0 = (-2.18 \pm 7.27) \times 10^{-5}$, *consistent with no temporal change. Combining these measurements with existing data, we find a spatial variation is preferred over a no-variation model at the 3.9* σ *level.*

To repeat: the difference from earthly value of α is small and consistent with no temporal change. If the measurements are combined with existing data, one finds that the model assuming spatial variation in north-south direction is preferred over no-variation model at 3.9 sigma level.

The presence of N-S direction looks very strange and counterintuitive and the effect might disappear: there are many uncertainties involved since data from several experiments are combined. If the effect is real, there is challenge to understand it so that one cannot avoid the temptation for intellectual exercise.

In TGD framework many-sheeted space-time serves as a starting point.

1. The notion of space-time sheet requires that the M$^4 projection of space-time surfaces is 4-D: I call these space-time sheets Einsteinian. This was not true in primordial cosmology during which cosmicst$
DM^4 projection dominated (2-D in good approximation) - space-time was not Einsteinian yet. During the analog of inflationary period cosmic strings thickened to flux tubes and liberated energy giving rise to ordinary particles. Transition to radiation dominated cosmology took place during this period.

2. The fluctuations in the density of matter tell that this transition did not take at exactly the same value of cosmic time T but there are fluctuations of order $/T \simeq 10^{-5}$. This happens to be same order of magnitude as the reported value of $\Delta\alpha/\alpha$ along North-South direction, which puts bells ringing. Could same cosmic parameter determine fluctuation amplitude $/T$ and the relative change $\Delta\alpha/\alpha$ along N-S direction?

Could it be that the transition to radiation dominated cosmology took place in a wave propagating in North-South (N-S) direction so that there would be a gradient of T along N-S direction: $/T$ - not fluctuation. This does f not require gradient in fluctuations $\Delta T/T$ and $\Delta\rho/\rho$. Could this gradient also explain the gradient in measured α along N-S direction?

How the N-S gradient in α could be understood?

1. At QFT limit particle experiences the sum of induced gauge fields assignable to the space-time sheets which it necessarily touches because it has same size of order CP_2 size as the sheets on top of each other in CP_2 directions. Standard model gauge fields can be indeed defined as sums of these induced gauge fields. Same applies to gravitational field identified in terms of metric of Einsteinian space-time having 4-D M^4 projection.

2. The many-sheeted space-time was not quite the same thing in today and in ancient universe. The number of space-time sheets could have been different. Space-time sheets carried also induced classical fields with different strength.

   Monopole flux tubes created during the analog of inflationary period from cosmic strings indeed evolve during cosmic evolution. Their thickness increases in rapid jerks and in average sense this corresponds to a smooth cosmic expansion. This conforms with the fact that astrophysical objects do not seem to expand themselves in cosmic expansion although they co-move as particles in this expansion.

   The increase of the thickness of monopole magnetic flux tube reduces its magnetic field strength since monopole flux is conserved. This in turn reduces the contribution of this space-time sheet to the classical em field experienced by a charged particle. In particular, this would affect the binding energies of atoms slightly.

3. Could this together with the wave like progression of the transition to radiation dominated cosmology be responsible for the dependence α on N-S direction with the increase $\Delta\alpha/\alpha \simeq 10^{-5}$?

4.6 The Problem Of Fermion Families

The generation-genus correspondence implies that the number of the particle families is apparently infinite. The arguments developed in the second part of the book however suggest that $g > 2$ particle families have masses of order $m_0 \sim 10^{-3.5} m_{Pl}$ except possibly at the very early stages of the cosmology in the vapor phase. One should somehow understand how the effective number of particle families manages to be finite and whether very early TGD inspired cosmology allows infinite number of light particle families. In the following I shall consider the possibility that the existence of the vapor phase might provide solutions to this problem.

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

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

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

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

number of fermion families is effectively finite and equal to three if the argument based on elementary particle vacuum functionals holds true.

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

It has turned out [K5] that under very general conditions the number of fermion families is three. The idea is that the property of being fermion has some space-time correlate. There are reasons to believe that this correlate is Z_2 conformal symmetry for the corresponding partonic 2-surfaces. This symmetry implies that fermionic elementary particle vacuum functionals vanish identically for $g > 2$. This holds true also for gauge bosons which can be regarded as fermion anti-fermion pairs associated with the light-like throats of wormhole contact. The argument is represented in detail in [K5].

4.7 The Redshift Anomaly Of Quasars

There are strange findings about the time dilation of quasar dynamics challenging the standard cosmology [E37]. One expects that the farther the object is the slower its dynamics looks as seen from Earth. Lorentz invariance implies red shift for frequencies and in time domain this means the stretching of time intervals so that the evolution of distant objects should look the slower the longer their distance from the observer is. In the case of supernovae this seems to be the case. What was studied now were quasars at distances of 6 and 10 billion years and the time span of the study was 28 years [E39]. Their light was red shifted by different amounts as one might expect but their evolution went on exactly the same rhythm. This looks really strange.

One must notice that the frequency assigned to electromagnetic signature is not ordinary light frequency. For instance, is it analogous to a frequency assignable to massive particle or massless particle? Consider ordinary Doppler effect as an analog. If the redshift is effectively that of a massive particle then the redshift is given by $f \rightarrow (1-v^2)^{1/2}f = (1+z)f$ and for small relative velocities the redshift is about $z = \Delta f/f = v^2$ smaller than for massless case $f \rightarrow ((1-v)/(1+v))^{1/2} \times f = zf$ giving $z = \Delta f/f = v$ in the same approximation. In the recent case however redshifts are large. From $z+1 = Hr$, with redshift $z = 7$ associated with $r = .75$ billion years one deduces $z = 56$ for 6 billion ly and $z = 93.3$ for 10 billion ly. Therefore the redshifts for massive and massless case are related by a factor of 2 as one easily finds.

Consider now the situation in TGD framework.

1. Causal diamond defined as the intersection of future and past directed light-cones is the fundamental geometric object in zero energy ontology. In cosmological scales a possible interpretation of CD is as sub-cosmology. In particular, our comology would correspond to this kind of CD having sub-CD s having.... CDs possess moduli space. CD has M^4 position identified as say that of the lower tip. One can perform Lorentz boosts for CD leaving the lower tip invariant. The proper time distance between tips of CD is Lorentz invariant and defines an internal time standard of CD. For instance, for electron, d, and u quarks this time is.1 seconds, 1/1.28 milliseconds, and 6.5 milliseconds corresponding to masses.5 Mev, 5 MeV, and 2 MeV [C9].These time scales define fundamental biorhythms [K28].

2. p-Adic length scale hypothesis follows if the light-cone proper time distance between the tips of the CD is quantized in powers of two. This means that future light-cone is replaced with a union of light-cone proper time constant hyperboloids with size scales coming as powers of two. Cosmic time in quantum cosmology identified as the distance between the tips would be quantized and cosmic time would increase in jumps. As a matter fact, the relative coordinate between the tips should be quantized quite generally so that the light-cone proper time constant hyperbloids would be replaced with discrete lattice like structures. This would predict quantization of cosmic redshifts and explain the claimed strange phenomena like God's fingers containing galaxies along the line of sight with a quantized redshift.

3. Could the quantization of the cosmic time relate to the strange observation? What does the dynamics of objects with a frozen value of cosmic time look like when viewed from Earth? What is clear that the distant object does not recede away during the studied evolution

period. The overall redshift for the studied events during its evolution is same. No dilation of the time interval between periodic events would takes place. But isn't this the case in good approximation also in the measurements? And obviously this argument does not say anything about the time dilations associated with the samples at different distances.

4. Let us make a second trial. The above idea that the observed system behaves like a particle would make sense at the level of sub-CD assignable to it. One can perform Lorentz boosts to the CD and from the point of view of observer this induces a dilation of the time scales of internal dynamics expressible as fractions of the proper time distance between its tips. Should one speak about two kinds of redshifts: the cosmic redhift associated with all radiation coming from the CD and the internal redshift associated the dynamics of CD. The observations about supernovae would suggests that cosmic expansion implies CDs of distant objects have systematically suffered a radial Lorentz boost in radial direction in the manner dictated by Hubble's law.

   This means that the time-like direction defined by the vector connecting tips of CD in M^4 is same as the time direction in co-moving system thus a time-like vector pointing from the tip of the very big CD defining what we call our Big Bang cosmology at this moment to the M^4 point at which the CD containing astrophysical object is located. This position characterizes all points of given CD so that the time dilation is same the for internal dynamics inside the CD.

5. Why the Lorentz boosts of quasar CDs in the two samples should be identical? Could the explanation relate to the fact that quasars are extremely distant objects meaning that the corresponding CDs are very large? Could the quasars in the two samples belong to the same CD?! If so then the internal dynamics would obey same rhythm but there would be a purely cosmological redshift! This effect would be basic prediction of zero energy ontology in cosmological scales and would become visible in very long length scales.

5 Matter-Antimatter Asymmetry, Baryo-Genesis, Lepto-Genesis, And TGD

The generation of matter-antimatter asymmetry is still poorly understood. There exists a multitude of models but no convincing one. In TGD framework the generation of matter-antimatter asymmetry can be explained in terms of cosmic strings carrying dark energy identified as Kähler magnetic energy. Their decay to ordinary and dark matter would be the analog for the decay of the inflaton field to matter and the asymmetry would be generated in this process. The details of the process have not been considered hitherto.

The stimulus for constructing a general model for this process came from attempt to understand the notion of sphaleron [B4] claimed to allow a non-perturbative description for a separate non-conservation of baryon and lepton numbers in standard model. The separate non-conservation of B and L would make possible models of baryo-genesis and even lepto-genesis assuming that in the primordial situation only right-handed inert neutrinos are present. To my opinion these models however fail mathematically because they equate the non-conservation of axial fermion numbers - which is on a mathematically sound basis - with the non-conservation of fermion numbers. This kind of assumption is unjustified and to my opinion is misuse of the attribute "non-perturbative".

The basic vision about lepto-genesis followed by baryo-genesis is however very attractive. This even more so because right-handed neutrino is in a completely unique role in TGD Universe. The obvious question therefore is whether this vision could make sense also in TGD framework. It would be wonderful if cosmic strings - infinitely thin Kähler magnetic flux tubes carrying magnetic monopole field, which later develop finite sized and expanding M^4 projection - carrying only right-handed neutrinos were the fundamental objects from which matter would have emerged in a way analogous to the decay of vacuum expectations of instanton fields. Even better, Kähler magnetic energy has interpretation as dark energy and magnetic tension gives rise to the negative "pressure" inducing accelerated expansion of the Universe.

The basic question is whether B and L are conserved separately or not. In TGD Universe one can consider two options depending on the answer to this question. For option I - the "official" version of TGD - quarks and leptons correspond to opposite 8-D chiralities of the induced spinor fields and B and L are conserved separately. For option II [K6] only leptonic spinor fields would be fundamental, and the idea is that quarks could be fractionally charged leptons. This option could lead to genuine baryo-genesis, and in the simplest model baryons would be generated from 3-leptons as 3-sheeted structures for which fractionization of color hyper-charge occurs. Leptonic embedding space spinors moving in triality zero color partial waves would be replaced with triality ± 1 partial waves assigned with quarks. Whether this replacement is on a mathematically sound basis, is far from obvious since induced spinor fields at space-time level would couple to induced spinor fields with leptonic couplings.

In any case, one can check whether leptogenesis, baryogenesis, and matter antimatter asymmetry are possible for either of both of these options. It turns out that for both option I and II one can construct simple model in terms for the generation of quarks from leptons via emission of lepto-quarks analogous to gauge bosons but differing from their counterparts in GUTs. Option II allows also genuine baryogenesis from leptons. The conclusion is that the "official" version of TGD predicting separate conservation of B and L allows an elegant vision about the generation of matter from cosmic strings containing only right-handed neutrinos in the initial states.

5.1 Background

A brief summary about conditions for the generation of matter-antimatter asymmetry and some of existing theories explaining it is in order.

5.1.1 Basic conditions for the generation of matter-antimatter asymmetry by baryon number generating interaction

The basic conditions for the generation of matter-antimatter asymmetry by baryon number generating interaction (see `http://tinyurl.com/62t6s6k`) [B1] were deduced by Saharov and are following.

1. Baryon number non-conservation.

2. C breaking and CP breaking. Matter-antimatter asymmetry requires these symmetry breakings.

3. Thermal non-equilibrium which naturally corresponds to a phase transition. In a typical cosmological situation the reactions responsible for preserving thermal equilibrium become slower that the rate for the cosmological expansion so that the particles participating the reactions decouple from each other and from thermal equilibrium. Otherwise these reactions destroy matter-antimatter asymmetry.

Also scenarios in which baryon number and lepton number are conserved are possible - TGD in its standard form allows one such option. The basic idea is that the universe decomposes into regions dominated by matter or antimatter. If slight matter-antimatter asymmetries - necessarily of opposite sign - are generated in region and its environment, the annihilation of particles and antiparticles leads to a situation in which there is only matter or antimatter present in both regions. If cosmic strings correspond are carriers of dark energy decaying to dark matter, they correspond naturally to the regions, where the asymmetry is generated. These cosmic strings could correspond "big" cosmic strings (magnetic flux tubes) going through large voids or the strings containing galaxies like pearls in necklace along them [K7] [L2]. Cosmic strings would serve as seats of antimatter whereas the surrounding regions would contain matter. What is lacking is a more detailed view about how cosmic strings burn to ordinary and dark matter and the identification of an exact mechanism for the generation of matter-antimatter asymmetry.

5.1.2 Generation of matter-antimatter asymmetry in GUTs and standard model

Most of models for the generation of matter anti-matter asymmetry rely on GUT philosophy and give up the assumption about separate conservation of B and L so that these these theories are also theories of baryo-genesis (for the theories of baryo-genesis (see `http://tinyurl.com/ycbk6jjw`) see the article by Riotto [B7]). For GUTs the non-conservation is present at the level of action but there is also a proposal that standard model could accommodate the non-conservation non-perturbatively.

1. In a typical model B and L are not conserved separately. Only B-L is conserved (the convention is that proton has B=1, and electron L=1). B and L are defined as vectorial fermion numbers. Axial B and L are not conserved for massive fermions and Higgs mechanism leads to the massivation of a theory which is originally massless.

2. In GUTs one arranges quarks and leptons of given generation into same multiplet. This implies that B and L are not conserved separately whereas B-L is. The exchanges of lepto-quarks (gauge bosons) assumed to have mass of order 10^{-4} Planck masses (of order CP_2 mass) induce proton decay. No proton decays have been observed yet and this has led to a fine-tuning of the parameters of these theories to avoid too fast proton decay.

Some theoreticians believe that even standard model could allow to understand baryo-genesis and generation of matter-antimatter asymmetry. Instanton (see `http://tinyurl.com/3s5dphr`) [B3] and sphaleron (see `http://tinyurl.com/y8atcgwc`) [B4] (see also the introductory article about sphalerons (see `http://tinyurl.com/y8xf6uyr`) [B12] and conference slides (see `http://tinyurl.com/yamdws4a`) [B6] about instantons/sphalerons and possible new physics within standard model)are the key notions of this approach. Perturbative approach to standard model predicts that both vectorial and axial quark and lepton numbers are separately conserved for massless fermions. The non-conservation of B and L is claimed to have a non-perturbative origin. The picture is roughly following.

1. Axial fermion numbers are not conserved for massive fermions even when the mass results from Higgs mechanism. Non-conservation is due to the fact that axial gauge symmetries are not genuine symmetries quantum mechanically because the integration measure for the path integral is not invariant under the axial gauge symmetries for which left and right handed fermions have opposite gauge charges.

2. By using refined topological arguments one can express the divergence $D_\mu A^\mu$ (see `http://tinyurl.com/y7ooddnf`) for the axial fermion current in terms of so called instanton density for the gauge field [B2]. Each fermion family gives a similar contribution to the divergence. One can calculate the changes of axial fermion numbers for an instanton connecting two states as the integral of instanton density reducing to the difference of so called Chern-Simons charges for final and initial field configurations.

   A numerical study of the situation using lattice gauge theories is possible (see `http://tinyurl.com/y7owcxko`) [B10] and provides information about rates for the appearance of instantons. Axial B-L is still conserved because the divergence of axial current is same for all fermions. Anomaly argument does not however force the non-conservation vectorial B and L (briefly B and L) and perturbatively they are conserved: here the weakness of the standard model approach obviously lies.

3. As noticed, the notion of instantons is crucial for the approach. Instantons are solutions of pure YM field equations (without Higgs field) in 4-D Euclidian 4-sphere S^4 or Euclidian space E^4: the Wick rotation to M^4 is of course mathematically and physically questionable step. Instantons connected two field configuration characterized by different Chern-Simons charges. The change of the Chern-Simons charge is integer valued. One can say that instantons transform two topologically non-equivalent vacua to each other. The proposed interpretation is that instanton tranforms incoming Dirac sea so that filled vacancy representing fermion with definite handedness becomes superposition of a hole and filled vacancy (fermions of opposite handedness). This would lead to the non-conservation of axial fermion numbers. It is important to stress again that the fermion numbers are axial - not vectorial- and that fermion number non-conservation does not follow from the presence of instantons alone.

4. The notion of sphalerons is a related concept. Sphalerons are static but unstable solutions of YM equations in Euclidian space E^4 in presence of Higgs field and are interpreted as a signature for the phase transition leading to generation of baryons from leptons. Since in Euclidian metric time and space do not differ in any manner, one can interpret one of the

spatial directions as time direction so that the situation becomes dynamical. Since there is a change of the sign of the Higgs vacuum expectation between diametrically opposite points of sphere S^3 at infinity, there is also a change of Higgs vacuum expectation in time direction. With a sufficient amount of good will one can say that sphaleron connects to in-equivalent local Higgs vacua. Sphaleron is hoped to give a simplified description of the situation, which might have something to do with reality.

5. The vision about non-perturbative breaking of baryon conservation has inspired models for the generation of matter-antimatter asymmetry and for how originally purely leptonic state generates baryons.

These models can be however criticized for sloppy mathematics.

1. The additional assumption that the change of the axial fermion number equals to the change of the vectorial fermion number is highly questionable and actually forces non-conservation of B and L by hand. To me this assumption looks like a misuse of the attribute "non-perturbative". This assumption can hold true only if one assumes that the fermionic handedness correlates with the sign of ΔQ_{C-S}. The instanton region would contain only left or right handed fermions depending on the sign of the integer characterizing instanton.

2. It is difficult to imagine what the non-conservation of (vectorial) B and L could mean in terms of particle reactions. Why not to be happy with what good mathematics gives: B and L are conserved and only axial fermion numbers fail to do so? This is perfectly natural since axial fermion numbers are opposite for right and left handed fermions. If this is accepted, baryo-genesis and related generation of matter-antimatter asymmetry are impossible in standard model framework.

3. Also the allowance of anomalies in path integral measure is questionable. For instance, in super string models the basic condition selecting the various candidates is that anomalies are absent.

The idea that leptons could transform to baryons in or without presence of instantons and at the same time generate matter-antimatter asymmetry is very attractive, and one one can wonder whether one could find a more coherent theoretical framework allowing this. The most ambitious models based on a small modification of it assume the existence of inert right-handed neutrinos (for which there is some cosmological support). They would have been the only particles present during the primordial phase and would have have generated leptons, which in turn have generated baryons by instantons. This idea is especially interesting from TGD point of view since right-handed neutrinos are in completely exceptional role in TGD Universe and the phase consisting of them possesses 4-D generalization of conformal SUSY (much large symmetry algebra than ordinary super-conformal algebra of M^4) so that the generation of matter from right handed neutrinos would have interpretation as breaking of this gigantic super-conformal symmetry.

5.2 Could TGD Allow Matter-Antimatter Asymmetry And Baryo-Genesis?

What makes the idea about non-conservation of B attractive is that TGD allows two variants.

1. For Option I quarks and leptons correspond to different chiralities of H spinors. Chirality is now not M^4 chirality (handedness) but 8-D H-chirality. B and L are separately conserved and proton is stable against decays predicted by GUTs.

   A possible but rather weak objection is following. The naïve expectation is that various bosons come in two varieties. Vector bosons in 8-D sense would couple to 8-D vector currents and thus have same coupling to both quarks and leptons. Axial bosons in 8-D sense would couple to 8-D axial currents and have opposite couplings to quarks and leptons. Axial and vectorial bosons can of course mix but one would expect more bosons than observed (W bosons are vectorial in 8-D sense, photon and Z^0 couple are mixtures of axial and vector bosons, and gluons in TGD framework couple vectorially (also leptons are predicted to have colored excitations).

2. For Option II only leptons appear as fundamental fermions. Leptons instead of quarks are favored by the supersymmetry (actually super-conformal symmetry) generated by right-handed neutrinos. In fractional quantum Hall effect (FQHE) charge fractionization takes place and this inspires the question whether quarks inside hadrons could be leptons with fractional charge. I considered this already around 2005 as a side product of work with hyper-finite factors of type II_1 [K6].

   Charge fractionization would result from the replacement $Q_L \rightarrow Q_L - 1/3$ for antileptons. Lepton number would the only conserved quantity and quarks and baryons could result by a phase transition in which leptons would somehow transform to quarks or to baryons.

   This raises several questions. What charge fractionization means? What lepto-quarks could be? What is this phase transition?

5.2.1 Could the option assuming only leptonic spinors make sense?

The stability of proton supports Option I but since only lower bounds for proton lifetime can be deduced experimentally, one must be ready to consider also Option II.

1. One cannot deny the attractiveness of the idea that quarks could be fractionally charged variants of leptons. For this option the process leading to the generation of baryons would not break any conservation laws and the mathematically highly questionable anomalous path integral would not be needed. In fact, path integral over gauge fields is replaced with functional integral over 3-surfaces in TGD framework.

2. Right-handed neutrino behaves like inert neutrino and in TGD ν_R has a unique role. The reason is that the conservation of electric charge forces to assume that all fermions except purely right-handed neutrino are localized at 2-D surfaces, "string world sheets". Pure right-handed neutrino is de-localized at entire space-time sheets - which could be identifiable magnetic flux tubes assignable to elementary particles. ν_R can give rise to a SUSY, which is however not the $\mathcal{N} = 1$ SUSY considered usually - almost excluded at LHC at TeV energy scale. The reason is that 8-D spinors cannot be Majorana spinors (see `http://tinyurl.com/y75omzhq`) [B5]. Right-handed neutrino obeys also maximal super-conformal symmetry extending 2-D conformal symmetry to $D = 4$ [K40] so that the generation of matter could be seen as a symmetry breaking.

3. One can indeed imagine a scenario in which right handed neutrinos mix with left-handed neutrinos localized at string world sheets. The weak interactions of left handed neutrinos (or actually mixtures of right and left handed neutrinos) would generate other leptons. Leptonic phase could in turn generate fractionally charged quarks (or baryons) and hadronization would lead to generation of baryons and other hadrons.

   This vision can be coupled with the earlier proposal for how matter-antimatter asymmetry is generated. Right handed neutrinos could reside at magnetic flux tubes representing cosmic strings and the process leading to generation of leptons and quarks would take place here.

5.2.2 What it could be to be a fractionally charged lepton?

For option I quark-like and leptonic spinors appear at both space-time level and embedding space level.

1. At space-time level one has second quantized induced spinor fields satisfying Kähler-Dirac equation. The condition that modes have well-defined electromagnetic charge together with the fact that classical W fields are present and mix different em charges implies that this condition can be satisfied only if the induced spinor fields are localized at 2-D surfaces - string world sheets. Right-handed neutrino is an exception and de-localized into entire space-time sheet. The functional integral over preferred extremals gives rise to a perturbative expansion in terms of fermionic propagators when one expresses the spinor modes as functionals of space-time sheet of preferred extremal [K40].

2. Embedding space spinors identified as leptonic and quark spinors differ in one aspect only. Their coupling to CP_2 Kähler gauge potentials is $n = -1$ for quarks and $n = 3$ for leptons. Embedding space spinors can be assigned to the center of mass degrees of partonic 2-surfaces (or possibly the position of the tip of CD associated with fermion). Spinor modes represent the ground states for the representations of the symplectic algebra of $\Delta M^4_\pm \times CP_2$ and also for the representations of Kac-Moody algebra associated with isometries and deforming on the light-like orbits of partonic 2-surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian.

   For leptons the spinor harmonics correspond to triality zero ($t = 0$) color partial waves in CP_2. For quarks the spinor harmonics correspond to $t = \pm 1$ color partial waves. These modes do not correspond directly to the physical quarks and leptons. States with correct correlation between electro-weak and color quantum numbers are obtained by allowing the action of the colored generators of the symplectic algebra on the physical states. The state construction is represented in [K19].

At the space-time level, where the fundamental spinorial dynamics takes place, the coupling of fermions to the Kähler gauge potential must be unique. If only single fermionic chirality is present, it must be either $n = 3$ or $n = -1$ and $n = 3$ is favored by the possible SUSY generated by right-handed neutrino.

What about embedding space level? How could the above picture of option I change if one assumes that only leptonic spinors are present at the space-time level?

1. For Option I it is natural to assume that the induced space-time spinors correspond to embedding space spinors with the same chirality and same value of n. Could one loosen this correspondence? Could embedding space spinors, which are not second quantized, and are assigned to cm degrees of freedom, be associated with embedding space spinor having both $n = -1$ and $n = 3$ for fermions.

   (a) Are these two state basis orthogonal? Certainly not as CP_2 spinors. As vacua for WCW spinor fields this could be the case if there is some topological distinction between the 3-surfaces assignable with these state basis. The idea about fractionization of charges (color hyper-charge) suggests that for quark states the space-time surface are 3-valued maps of CP_2 to M^4 analogous to Riemann surface of $z^{1/3}$ so that a color hyper-charge rotation of 2π in CP_2 (say at homologically non-trivial geodesic sphere of CP_2 defining coordinates of the partonic 2-surface) does not lead to the original point and only the rotation by 6π does this. This would be an analog for spin fractionization. This could justify the use of quark spinor harmonics for the embedding space spinors.

   (b) Could the two state basis be non-orthogonal and provide alternative state basis? Many-quark states can correspond to many-lepton states only if the differences $N_q - N_{\overline{q}}$ of numbers of quarks and antiquarks is a multiple of 3 so that the many-fermion state has triality $t = 0$. Color confinement is consistent with this condition and implies it. This option does not look attractive and will not be assumed in the sequel.

2. A serious problem is caused by the $n = -1$ coupling of the induced leptonic spinor fields. Internal consistency could quite well force the embedding space spinors to have the same coupling.

5.2.3 How leptons could transform directly to baryons for Option II?

If the direct transformation of leptons to quarks identified as fractionally charged leptons is possible, it must be non-perturbative in the sense that it involves several leptons and quarks simultaneously in order to satisfy the conservation of color and em charge. Since the resulting many quark state must have a vanishing triality, the number of quarks and therefore also leptons must be a multiple of 3. The simplest situation corresponds to a transformation of 3 leptons to 3 quarks forming a color singlet - perhaps identifiable as baryon.

The geometric view about color spin fractionization suggests that three leptonic space-time sheets defining 1-fold coverings of CP_2 fuse to from a 3-fold covering of CP_2 (so that M^4 coordinates are 3-valued as functions of CP_2 coordinates). The proposed explanation for the effective hierarchy of Planck constants $\hbar_{eff} = n\hbar$ is in terms of n-furcations of 3-surface: the recent case might correspond $n = 3$. Each sheet of the covering would carry lepton number 1. These 3-quark states would be only a special case of more general states containing $n = 1, 2$ or 3 quarks at the 3-sheeted structure.

In the process transforming 3 anti-leptons to baryon - say proton - one unit of em charge must be carried away and W^+ boson could do this. In the reverse process proton would decay to 3 leptons and W^- boson. $W^\pm$ boson must be virtual and absorbed by another particle so that weak interactions are also involved. The probability for this process must be very low, probably much lower than beta decay rate (I do not know whether possible decays of baryon to leptons and W boson have been studied). This means that the coupling for the fusion vertex must be very small.

If this picture is correct, the key non-perturbative element would be a phase transition changing the effective value of $\hbar$ to $3\hbar$. These phase transitions for large values of n are essential in the TGD inspired model of living matter. There is also a proposal that gravitons possess a very large value of $\hbar$ and decay to bursts of ordinary gravitons. This could explain the failure to observe gravitational waves [K26]. This mechanism forces to consider a geometric description of proton as a 3-sheeted structure presumably assignable to the magnetic body of proton.

It is too early to say whether this picture is consistent with the existing view about hadrons in which quarks space-time sheets are assumed to be connected by Kähler-magnetically charged color flux tubes. Also the question whether quarks understood as 3-sheeted structures containing only single quark could be allowed remains open. In any case, many-quark states must have triality zero so that quark number must be a multiple of 3.

5.2.4 Generation of matter-antimatter asymmetry without breaking the separate conservation of B and L

Cosmic strings dominate the TGD inspired cosmology [K31] during the primordial period after which a phase transition leading to radiation dominated cosmology takes place. The transformation of neutrinos to leptons inside cosmic strings which in turn decays to quarks and lepto-quarks which partially leak out from the system is an attractive mechanism for the generation of matter-antimatter asymmetry.

The mechanism to be discussed conserves B and L and thus works for option I. It works also for option II, if it makes sense to speak about quarks rather than only color singlet bound states of quarks formed as 3-sheeted structures with quark number 3, and treat quarks as independent objects. Many-quark states must however have quark number coming as a multiple of 3.

What can one say about the transformation of leptons to quarks by lepto-quark emission?

1. The charges of lepton and corresponding quark are different but this not a problem if one assumes the existence of lepto-quarks identified as gauge boson like states with quark (lepton with fractional charge) and lepton at opposite wormhole throats. For option I there is no reason why leptoquarks could not exist.

2. The most general assumption is that all possible combinations of quarks and leptons are allowed. Lepto-quarks qL and $\overline{q}\overline{L}$ have vanishing B-L for option I and vanishing L for option II: this makes them highly analogous to gauge bosons for option II. Lepto-quarks $q\overline{L}$ and $\overline{q}L$ have vanishing B+L for option I and have L=2 for option II. In the following only the option involving only qL and $\overline{q}\overline{L}$ is considered but the arguments generalize to the remaining cases trivially.

3. The transformation of antilepton to quark would take place by emission of lepto-quark $\overline{L}\overline{q}$ taking care of the conservation of various quantum numbers. The exchange of lepto-quarks is B and L conserving process and cannot lead to a decay of proton. It however predicts a new and presumably very slow decay channel for the decay of proton-antiproton pair to leptons.

   In the transformation $e^- \rightarrow \overline{u}$ a lepto-quark e^-u with charge $-1/3$ is emitted. In the transformation $e^- \rightarrow \overline{d}$ lepto-quark e^-d with charge $-4/3$ is emitted. More generally, $L \rightarrow \overline{q}$

proceeds via the emission of Lq type lepto-quark. Note that the lepton number of the lepto-quark vanishes for option II so that it represents an ordinary gauge boson with vanishing fermion number.

4. What happens to the emitted lepto-quarks? The lepto-quark can decay to $L + q$ so that the situation is the original one plus quark antiquark pair unless the lepto-quark has leaked outside the cosmic string. It the decay occurs inside cosmic strong, the process can continue and in principle single lepton or anti-lepton can generate a larger number of $q\overline{q}$ pairs. Kinematically these decays are not possible for ordinary on mass shell leptons but TGD allows the existence of scaled up copies of leptons, say leptons characterized by Mersenne prime M_{89} having mass scale about $2^{(127-89)/2}m_e \simeq 250$ GeV. These leptons could generate ordinary quarks through their decays.

5. This mechanism alone cannot generate matter-antimatter asymmetry. Suppose that the rates for the decays $\overline{L} \rightarrow q + \overline{Lq}$ are slightly lower than those for $L \rightarrow \overline{q} + qL$. A surplus of lepto-quarks Lq over $\overline{Lq}$ is generated. If there is a transfer of lepto-quarks Lq and their antiparticles from the interior of cosmic string to the environment and transfer rates are same, more Lq: s are transferred and their decays generate a net density of quark and lepton numbers in the environment. Inside cosmic string net density of opposite sign is generated by B and L conservation.

6. If the decay rate of lepto-quark is of order g^2M with M of order CP_2 mass, leakage is possible if the M^4 projection of the cosmic string is below $1/g^2M_{CP_2}$. Therefore the process could become active after the cosmic string dominated primordial period and could be associated with the phase transition from string dominated phase to radiation dominated phase during which space-time sheets corresponding to preferred extremals with large 4-D M^4 projection in the transversal scale of cosmic string emerge. Since the process conserves B and L separately, it could however take place also in much longer p-adic length scales.

   The masses of the lepto-quark could result from couplings to Higgs like bosons but the mass scale of the vacuum expectation value inside cosmic string corresponds to a rather small p-adic prime instead of M_{89} for weak interactions. Mersenne primes are the first guess for p-adic primes assignable to gauge bosons and $M_7 = 127$ is a reasonable guess for the p-adic prime during the transition to radiation dominated phases.

The conclusion is that lepto-quark mechanism works for both Option I and II and therefore Option II is not needed to understand generation of matter-antimatter asymmetry or even leptogenesis and baryogenesis. This does not of course mean that Option II would be necessarily excluded.

5.2.5 Generation of matter asymmetry accompanied with a genuine baryo-genesis for option II

One can also consider a generation of matter-antimatter asymmetry and baryo-genesis based on fusion of leptons to baryons by the proposed mechanism for the formation of baryons from anti-leptons at cosmic strings. If the rates for the fusion process are different for leptons and anti-leptons, a net density of baryon number is generated in environment.

Suppose that in the interior of cosmic string anti-leptons transform to baryons with a rate slightly higher that leptons to anti-baryons. As a consequence, the number densities of baryons and leptons become higher than those for anti-baryons and anti-leptons inside cosmic string. If the transfer rates for baryons and anti-baryons to environment are same, the outcome would be net density of baryon number in environment. The faster transfer of anti-leptons than leptons from environment to cosmic string induced by the larger density gradient would induce net density of lepton number in environment. As a consequence, opposite net densities of B and L in environment and interior of string would be generated.

5.2.6 Could all matter be generated from right-handed neutrinos at magnetic flux tubes?

The idea about leptogenesis (see `http://tinyurl.com/ychexeak`) [B9] initiated form right-handed neutrinos and followed by baryogenesis (see `http://tinyurl.com/62t6s6`) [B7] is highly attractive. TGD leads to the vision that matter and dark matter has been generated from dark energy identified as Kähler magnetic energy for magnetic flux tubes which have evolved from cosmic strings by the gradual thickening of M^4 projection [L2]. I have not yet considered any detailed model for this process.

Right-handed neutrino has a unique role in TGD framework [K40] and an attractive idea is that during primordial phase - and perhaps even at magnetic flux tubes evolved from them - the physics started from something extremely simple and symmetric: only magnetic flux tubes containing right-handed neutrinos. This situation would correspond to a 4-D extension of super-conformal symmetry [K40], and the emergence of string world sheets would reduce this 4-D to super-conformal symmetry to ordinary 2-D one. Other fermions localized at string world sheets would have emerged only after the mixing of right handed neutrino to mixtures of left and right handed neutrinos localized at string worlds sheets. Neutrinos in turn would decay to charged leptons and W bosons by weak interactions. The decay $L \rightarrow \overline{q} + Lq$ in turn would have generated baryons and matter-antimatter asymmetry for both options. For option II also the direct fusion of leptons to baryons or more general color singlet quark triplets could have occurred.

One should construct a model for the mixing of right- and left-handed neutrinos.

1. Mixing should reduce to fermionic propagation and be dictated by the dynamics of the Kähler-Dirac operator alone. The mixing amplitude would be obtained by calculating a transition amplitude between ν_R and ν_L located at partonic 2-surfaces at opposite ends of CD. This requires integration over CD inducing perturbation theory using fermionic propagator defined by the Kähler-Dirac action with coupling to WCW degrees of freedom via the gauge coupling to induced CP_2 spinor connection. ν_R propagates 4-dimensionally and the other leptonic modes only 2-dimensionally. Also the mixing of lepton generations induced by the mixing of the topologies of fermion number carrying partonic 2-surfaces must be taken into account.

2. The overall parameterization at the QFT limit would be in terms of a generalization of CKM matrix, which is known to be non-trivial and force also neutrino massivation in turn forcing mixing of the right- and left-handed neutrinos.

5.2.7 Conclusions

The cautious conclusion is that option I - that is the "official" version of TGD identifying quarks and leptons and two chiralities of embedding space spinors - leads to an elegant model for leptogenesis, baryogenesis, and generation of matter antimatter asymmetry and at the same time to a more detailed model for how the Kähler magnetic energy of magnetic flux tubes transforms to matter and dark matter. One cannot however exclude option II involving only leptons whose anyonic states would give rise to baryons.

6 Cosmic Evolution As Transformation Of Dark Energy To Matter

The proposed bubble option favored by the fact that Newtonian theory works so well inside planetary system favors bound state precessing solutions without nutation. These solutions are expected to be stable against dissipation. Small nutation around the equilibrium solution could explain the slow variation of the precession rate. The variation could be also caused by external perturbations. What is amusing from the mathematical point of view is that the model is analytically solvable and that the solution involves elliptic functions just as the Newtonian two-body problem does.

The model suggests a universal fractal mechanism leading to the formation of astrophysical and even biological structures as a formation of bubbles of ordinary or dark matter inside magnetic flux tubes carrying dark energy identified as magnetic energy of the flux tubes. In primordial cosmology these flux tubes would have been cosmic strings with enormous mass density, which is however below the black hole limit for straight strings. Strongly entangled strings could form black holes if general relativistic criteria hold true in TGD.

One must be very critical concerning the model since in TGD framework the accelerated cosmic expansion has several alternative descriptions, which should be mutually consistent. It seems that these descriptions corresponds to the descriptions of one and same thing in different length scales.

1. The critical and over-critical cosmologies representable as four-surfaces in $M^4 \times CP_2$ are unique apart from their duration [K31]. The critical cosmology corresponds to flat 3-space and would effectively replace inflationary cosmology in TGD framework and criticality would serve as a space-time correlate for quantum criticality in cosmological scales natural if hierarchy of Planck constants is allowed. The expansion is accelerating for the critical cosmology and is caused by a negative "pressure" basically due to the constraint force induced by the imbeddability condition, which is actually responsible for most of the explanatory power of TGD (say geometrization of standard model gauge fields and quantum numbers).

2. A more microscopic manner to understand the accelerated expansion would be in terms of cosmic strings. Cosmic strings [K7] expand during cosmic evolution to flux tubes and serve as the basic building bricks of TGD Universe. The magnetic tension along them generates a negative "pressure", which could explain the accelerated expansion. Dark energy would be magnetic energy.

   The proposed boiling of the flux tubes with bubbles representing galaxies, stars, ..., cells, etc.. would serve as a universal mechanism generating ordinary and dark matter. The model should be consistent with the Bohr orbitology for the planetary systems [K30] in which the flux tubes mediating gravitational interaction between star and planet have a gigantic Planck constant. This is the case if the magnetic flux tubes quite generally correspond to gigantic values of Planck constant of form $\hbar_{gr} = GM_1M_2/v_0$, $v_0/c < 1$, where M_1 and M_2 are the masses of the objects connected by the flux tube.

3. Even more microscopic description of the accelerated expansion would be in terms of elementary particles. In TGD framework space-time decomposes into regions having both Minkowskian and Euclidian signatures of the induced metric [K36]. The Euclidian regions are something totally new as compared to the more conventional theories and have interpretation as space-time regions representing lines of generalized Feynman diagrams.

   The simplest GRT limit of TGD relies of Einstein-Maxwell action with a non-vanishing cosmological constant in the Euclidian regions of space-time [K36]: this allows both Reissner-Nordström metric and CP_2 as special solutions of field equations. The cosmological constant is gigantic but associated only with the Euclidian regions representing particles having typical size of order CP_2 radius. The cosmological constant explaining the accelerated expansion at GRT limit could correspond to the space-time average of the cosmological constant and therefore would be of a correct sign and order of magnitude (very small) since most of the space-time volume is Minkowskian.

   This picture can be consistent with the idea that magnetic flux tubes which have Minkowskian signature of the induced metric are responsible for the effective cosmological constant if the magnetic energy inside the magnetic flux tubes transforms to elementary particles in a phase transition generating dark and ordinary matter from dark energy and therefore gives rise to various visible astrophysical objects.

7 The Origin Of Cosmic Rays

The origin of cosmic rays remains still one of the mysteries of astrophysics and cosmology. The recent finding of a super bubble (see `http://tinyurl.com/o5pgkb4`) [E35] emitting cosmic rays might cast some light in the problem.

7.1 What has been found?

The following is the abstract (see `http://tinyurl.com/yb8t3beb`) of the article published in Science [E15].

The origin of Galactic cosmic rays is a century-long puzzle. Indirect evidence points to their acceleration by supernova shockwaves, but we know little of their escape from the shock and their evolution through the turbulent medium surrounding massive stars. Gamma rays can probe their spreading through the ambient gas and radiation fields. The Fermi Large Area Telescope (LAT) has observed the star-forming region of Cygnus X. The 1- to 100-gigaelectronvolt images reveal a 50-parsec-wide cocoon of freshly accelerated cosmic rays that flood the cavities carved by the stellar winds and ionization fronts from young stellar clusters. It provides an example to study the youth of cosmic rays in a superbubble environment before they merge into the older Galactic population. The usual thinking is that cosmic rays are not born in states with ultrahigh energies but are boosted to high energies by some mechanism. For instance, super nova explosions could accelerate them. Shock waves could serve as an acceleration mechanism. Cosmic rays could also result from the decays of heavy dark matter particles.

The story began when astronomers detected a mysterious (see `http://tinyurl.com/pou4b83`)source of cosmic rays (see `http://tinyurl.com/pou4b83`) in the direction of the constellation Cygnus X [E11]. Supernovae happen often in dense clouds of gas and dust, where stars between 10 to 50 solar masses are born and die. If supernovae are responsible for accelerating of cosmic rays, it seems that these regions could also generate cosmic rays. Cygnus X is therefore a natural candidate to study. It need not however be the source of cosmic rays since magnetic fields could deflect the cosmic rays from their original direction. Therefore Isabelle Grenier and her colleagues decided to study, not cosmic rays as such, but gamma rays created when cosmic rays interact with the matter around them since they are not deflected by magnetic fields. Fermi gamma-ray space telescope was directed toward Cygnus X. This led to a discovery of a superbubble with diameter more than 100 light years. Superbubble contains a bright regions which looks like a duck. The spectrum of these gamma rays implies that the cosmic rays are energetic and freshly accelerated so that they must be close to their sources.

The important conclusions are that cosmic rays are created in regions in which stars are born and gain their energies by some acceleration mechanism. The standard identification for the acceleration mechanism are shock waves created by supernovas but one can imagine also other mechanisms.

7.2 Cosmic rays in TGD Universe?

In TGD framework one can imagine several mechanisms producing cosmic rays. According to the vision already discussed, both ordinary and dark matter would be produced from dark energy identified as Kähler magnetic energy and producing as a by product cosmic rays. What causes the transformation of dark energy to matter, was not discussed earlier, but a local phase transition increasing the value of Planck constant of the magnetic flux tube could be the mechanism. A possible acceleration mechanism would be acceleration in an electric field along the magnetic flux tube. Another mechanism is super-nova explosion scaling-up rapidly the size of the closed magnetic flux tubes associated with the star by $\hbar$ increasing phase transition preserving the Kähler magnetic energy of the flux tube, and accelerating the highly energetic dark matter at the flux tubes radially: some of the particles moving along flux tubes would leak out and give rise to cosmic rays and associated gamma rays.

7.2.1 The mechanism transforming dark energy to dark matter and cosmic rays

Consider first the mechanism transforming dark energy to dark matter.

1. The recent model for the formation of stars and also galaxies is based on the identification magnetic flux tubes as carriers of mostly dark energy identified as Kähler magnetic energy giving rise to a negative “pressure” as magnetic tension and explaining the accelerated expansion of the Universe. Stars and galaxies would be born as bubbles of ordinary are generated inside magnetic flux tubes. Inside these bubbles dark energy would transform to dark and ordinary matter. Kähler magnetic flux tubes are characterized by the value of Planck constant

and for the flux tubes mediating gravitational interactions its value is gigantic. For a start of mass M its value for flux tubes mediating self-gravitation it would be $\hbar_{gr} = GM^2/v_0$, $v_0 < 1$ (v_0 is a parameter having interpretation as a velocity).

2. On possible mechanism liberating Kähler magnetic energy as cosmic rays would be the increase of the Planck constant for the magnetic flux tube occurring locally and scaling up quantal distances. Assume that the radius of the flux tube is this kind of quantum distance. Suppose that the scaling $\hbar \rightarrow r\hbar$ implies that the radius of the flux tube scales up as r^n, $n = 1/2$ or $n = 1$ ($n = 1/2$ turns out to be the sensible option). Kähler magnetic field would scale as $1/r^{2n}$. Magnetic flux would remain invariant as it should and Kähler magnetic energy would be reduced as $1/r^{2n}$. For both options Kähler magnetic energy would be liberated. The liberated Kähler magnetic energy must go somewhere and the natural assumption is that it transforms to particles giving rise to matter responsible for the formation of star.

   Could these particles include also cosmic rays? This would conform with the observation that stellar nurseries could be also the birth places of cosmic rays. One must of course remember that there are many kinds of cosmic rays. For instance, this mechanism could produce ultra high energy cosmic rays having nothing to do with the cosmic rays in 1-100 GeV rays studied in the recent case.

3. The simplest assumption is that the thickening of the magnetic flux tubes during cosmic evolution is based on phase transitions increasing the value of Planck constant in step-wise manner. This is not a new idea and I have proposed that entire cosmic expansion at the level of space-time sheets corresponds to this kind of phase transitions. The increase of Planck constant by a factor of two is a good guess since it would increase the size scale by two. In fact, Expanding Earth hypothesis having no standard physics realization finds a beautiful realization in this framework. Also the periods of accelerating expansion could be identified as these phase transition periods.

4. For the values of gravitational Planck constant assignable to the space-time sheets mediating gravitational interactions, the Planck length scaling like $r^{1/2}$ would scale up to black-hole horizon radius. The proposal would imply for $n = 1/2$ option that magnetic flux tubes having M^4 projection with radius of order Planck length primordially would scale up to blackhole horizon radius if gravitational Planck constant has a value GM^2/v_0, $v_0 < 1$, assignable to a star. Obviously this evolutionary scenario is consistent with with what is known about the relations ship between masses and radii of stars.

7.2.2 What is the precise mechanism transforming dark energy to matter?

What is the precise mechanism transforming the dark magnetic energy to ordinary or dark matter? This is not clear but this mechanism could produce very heavy exotic particles not yet observed in laboratory which in turn decay to very energetic ordinary hadrons giving rise to cosmic rays spectrum. I have considered a mechanism for the production of ultrahigh energy cosmic rays based on the decays of hadrons of scaled up copies of ordinary hadron physics [K21]. In this case no acceleration mechanism would be necessary. Cosmic rays lose their energy in interstellar space. If they correspond to a large value of Planck constant, situation would change and the rate of the energy loss could be very slow. The above described experimental finding about Cygnus X however suggests that acceleration takes place for the ordinary cosmic rays with relatively low energies. This of course does not exclude particle decays as the primary production mechanism of very high energy cosmic rays. In any case, dark magnetic energy transforming to matter gives rise to both stars and high energy cosmic rays in TGD based proposal.

7.2.3 What is the acceleration mechanism of cosmic rays or is there any such mechanism?

How cosmic rays are created by this general process giving rise to the formation of stars?

1. Cosmic rays could be identified as newly created matter leaking out from the system. Even in the absence of accelerating fields the particles created in the boiling of dark energy to matter,

particles moving along magnetic flux tubes would move essentially like free particles whereas in orthogonal directions they would feel $1/\rho$ gravitational force. For large values of $\hbar$ this could explain very high energy cosmic rays. The recent findings about gamma ray spectrum however suggests that there is an acceleration involved for cosmic rays with energies 1-100 GeV.

2. One possible alternative acceleration mechanism relies on the motion along magnetic flux tubes deformed in such a way that there is an electric field orthogonal to the magnetic field in such a way that the field lines of these fields rotate around the direction of the flux tube. The simplest embeddings of constant magnetic fields allow deformations allowing also electric field [K18], and one can expect the existence of preferred extremals with similar structure. Electric field would induce an acceleration along the flux tube. If the flux tube corresponds to large non-standard value of Planck constant, dissipation rate would be low and the acceleration mechanism would be very effective.

   Similar mechanism might even explain the observations about ultrahigh energy electrons associated with lightnings at the surface of Earth: they should not be there because the dissipation in the atmosphere should not allow free acceleration in the radial electric field of Earth.

   Here one must be very cautious: the findings are based on a model in which gamma rays are generated with collisions of cosmic rays with matter. If cosmic rays travel along magnetic flux tubes with a gigantic value of Planck constant, they should dissipate extremely slowly and no gamma rays would be generated. Hence the gamma rays must be produced by the collisions of cosmic rays which have leaked out from the magnetic flux tubes. If the flux tubes are closed (say associated with the star) the leakage must indeed take place if the cosmic rays are to travel to Earth.

3. There could be a connection with supernovae although it would not be based on shock waves. Also supernova expansion could be accompanied by a phase transition increasing the value of Planck constant. Suppose that Kähler magnetic energy is conserved in the process. This is the case if the lengths of the magnetic flow tubes r and radii by $r^{1/2}$. The closed flux tubes associated with supernova would expand and the size scale of flux tubes would increase by factor r. The fast radial scaling of the flux tubes would accelerate the dark matter at the flux tubes radially.

   Cosmic rays having ordinary value of Planck constant could be created when some of the dark matter leaks out from the magnetic flux tubes as their expanding motion in radial direction accelerates or slows down. High energy dark particles moving along flux tube would leak out in the tangential direction. Gamma rays would be generated as the resulting particles interact with the environment. The energies of cosmic rays would be the outcome of acceleration process: only their leakage would be caused by it so that the mechanism differs in a decisive manner from the mechanism involving shock waves.

4. The energy scale of cosmic rays - let us take it to be about E=100 GeV for definiteness- gives an order of magnitude estimate for the Planck constant of dark matter at the Kähler magnetic flux tubes if one assumes that supernovae is producing the cosmic rays. Assume that electro-magnetic field equals to induced Kähler field (the space-time projection of space-time surface to CP_2 belongs homologically non-trivial geodesic sphere). Assume that E equals the cyclotron energy scale given by $E_c = \hbar eB/m_e$ in non-relativistic situation and by $E_c = \sqrt{\hbar eB}$ in relativistic situation. The situation is relativistic for both proton and electron now and at this limit the cyclotron energy scale does not depend on the mass of the charged particle at all. This means that same value of $\hbar$ produces same energy for both electron and proton.

   (a) The magnetic field of pulsar (see `http://tinyurl.com/y9uw4kae`) can be estimated from the knowledge how much the field lines are pulled together and from the conservation of magnetic flux: a rough estimate is $B = 10^8$ Tesla and will be used also now. This field is $2 \times 10^{12} B_E$ where $B_E = .5$ Gauss is the nominal value of Earth's magnetic field.

(b) The cyclotron frequency of electron in Earth's magnetic field is $f_c(e) = 6\times 10^5$ Hz in a good approximation and correspond to cyclotron energy $E_c = 10^{-14}(f_c/Hz)$ eV from the approximate correspondence $eV \leftrightarrow 10^{14}\ \ Hz$ true for $E = hf$. For the ordinary value of Planck constant electron's cyclotron energy would be for supernova magnetic field $B_S = 10^8$ Tesla equal to $E_c = 2\times 10^{-2}(f_c/Hz)$ eV and much below the energy scale $E = 100$ GeV.

(c) The required scaling $\hbar \rightarrow r\hbar$ of Planck constant is obtained from the condition $E_c = E$ giving in the case of electron one can write

$$r = (\frac{E}{E_c})^2 \times = \frac{B_E}{B_S} \times \frac{\hbar e B_E}{m_e^2} \quad .$$

The dimensionless parameter $\hbar e B_E/m_e^2 = 1.2\times 10^{-14}$ follows from $m_e = .5$ MeV. The estimate gives $r \sim 2\times 10^{12}$. Values of Planck constant of this order of magnitude and even larger ones appear in TGD inspired model of brain but in this case magnetic field is Earth's magnetic field and the large thickness of the flux tube makes possible to satisfy the quantization of magnetic flux in which scaled up $\hbar$ defines the unit.

To sum up, large values of Planck constant would be absolutely essential making possible high energy cosmic rays and just the presence of high energy cosmic rays could be seen as an experimental support for the hierarchy of Planck constants. The acceleration mechanism of cosmic rays are poorly understood and TGD option predicts that there is no acceleration mechanism to search for.

7.3 Too much deuterium in cosmic rays and too anti-helium that should not exist

The newest twist in the mystery of cosmic rays emerges from the findings described in the popular article "Cosmic count exceeds expectation" (see this) describing the findins of AMS detected at International Space Station challenge the standard narrative of stellar nuclear physics and of the origin of cosmic rays. There is a Physics Letters article [E16] (see this about the findings.

There is also evidence from AMS-2 for antideuteron and antihelium events, even in the case of anti ^4He. The evidence has been reported already 2022 [E41](see this). The presence of anti ^4He in the cosmic ray spectrum is especially difficult to understand and forces us to ask whether astrophysical objects consisting of antimatter do exist.

The standard story about cosmic rays goes as follows. The abundance of primordial deuterons is very small. Cosmic rays are either primary or secondary. Primary cosmic rays, such as would be formed in supernova explosions. Secondary cosmic rays such as deuteron and ^3He are formed in collisions of primary cosmic rays, in particular ^4He nuclei, with the interstellar medium.

7.3.1 Surplus of deuterium nuclei

The surplus of deuterium nuclei challenges this picture (there are also earlier findings of this kind). The flux of cosmic ray deuterons normalized to ^4He flux is larger than predicted at higher energies and at highest energies studied comparable to the proton flux. This is very strange since protons are primary cosmic rays.

This raises the question whether there is some other non-standard source of cosmic ray deuterons: arey these deuterons really secondary cosmic rays. This forces us to ask whether the nuclear physics of the Sun is what we believe it to be.

In fact, the mechanism producing nuclei heavier than Fe in supernova explosions is poorly understood and there are also anomalies in the abundances of the lighter nuclei. The standard narrative about the core of the Sun cannot be directly tested and indirect tests do not support it. Neutrino flux is too low and also the heat transfer by convection is quite too flow suggesting that the flux of nuclei from the core is much lower than predicted. There are many other anomalies challenging the idea that solar energy is produced in the core and the mechanism producing the solar wind. Is the solar interior what we believe it to be?

TGD leads to a radically new view of the physics of the Sun [L26]. In TGD view, the solar wind and solar energy would be produced in the decays of nuclear strings of predicted M_{89} nucleons with mass 512 times the mass of the ordinary nucleon at the monopole flux tubes of the magnetic field of the Sun to ordinary nuclei.

The proposal is that the decay mechanism is based on p-adic cooling in which the mass of the nucleon decreases by factor 1/2 in each step and the p-adic mass scale is reduced octave by octave (period doubling). This would produce ordinary nuclei of the solar wind with reasonable energies heating the medium and creating solar corona. This model forces us to completely change our view of the Sun and its interior since the energy and solar wind and even cosmic rays would be produced at its surface.

These decays would produce a huge amount of energy liberated as scaled up variants of ordinary hadrons, in particular the mesons of M_{89} physics. The mesons and gammas would eventually decay to ordinary mesons and gamma rays and importantly, also to nucleon-antinucleon pairs, maybe even deuteron-antideuteron pairs, maybe even helium-antihelium pairs for which AMS also provides evidence [E41](see this). This could explain the mysterious gamma ray anomalies of the Sun, suggesting that two new hadron physics are involved: M_{89} hadron physics and $M_{G,79}$ hadron physics (here "G" refers to Gaussian integers).

The decay mechanism of M_{89} nuclei at the stellar surfaces would not distinguish between secondary and primary cosmic rays and would produce cosmic rays, in particular deuterons. Could these decays serve as the origin of the cosmic rays.

7.3.2 What about the surplus of anti-deuterium and anti-helium nuclei?

One can imagine several mechanisms.

1. Could also the mysterious anti-deuterium and anti-Helium nuclei be understood as resulting from the decays of mesons for scaled up variants of the ordinary hadron physics appearing as intermediate steps in the p-adic cooling. Naive scaling suggests that scaled up pions with mass scaled up by the ratio, which is larger than $2m(^4He)/m(pion) = 8m_p/m(pion) \simeq 112$ are required. The mass scale of the interediated nuclei would be about $2^7 = 128$. They could correspond to a p-adic prime $p \sim 2^{93}$.

   It is however difficult to understand why the decay products would not consist of only nucleon-anti nucleon pairs. A fusion of these antinucleons to antinuclei would be required after the decay. If the emitted nuclei, which are nuclear strings in the TGD framework, propagate along the same flux tube this might actually take place.

2. A more elegant option is that the antimatter nuclei correspond to M_{89} antinuclear flux tubes, which decay to ordinary antinuclear strings by reconnection. This gives also antinuclei heavier than nucleon.

3. An alternative TGD inspired explanation relies on the TGD view of the matter antimatter asymmetry. There would be no actual asymmetry but by the CP violation there is a surplus of antimatter inside some monopole flux tubes and a surplus of matter in their environments. The obvious objection is that the asymmetry should be universal so that very long monopole flux tubes should carry antimatter.

   (a) Suppose that the antimatter can reside in this kind of flux tubes, perhaps as dark matter in the TGD sense. This would make possible the entire spectrum of nuclei as decay products from the splitting of the antimatter flux tube to pieces. Mechanism would be very similar to that proposed at the surface of the Sun and forces us to ask whether antistars could exist. As special case the flux tube could correspond to antinucleus perhaps M_{89} antinucleus.

   (b) One can also imagine other realizations. For instance, I have considered the possibility that the long monopole flux tubes giving rise to linear structures along which galaxies are located, could contain antimatter, perhaps as M_{89} anti nuclei. Note that if the M_{89} nucleons arrive at the Sun along flux tubes emerging from the galactic BH, then galactic BH would naturally consist of matter and anti nuclei should have some other source.

8 Quantum Fluctuations In Geometry As A New Kind Of Noise?

The motivation for writing the original variant of this section came from the email of Jack Sarfatti. I learned that gravitational detectors in GEO600 experiment have been plagued by unidentified noise in the frequency range 300-1500 Hz [E38]. Craig J. Hogan has proposed an explanation in terms of holographic Universe [E10]. By reading the paper I learned that assumptions needed might be consistent with those of quantum TGD. Light-like 3-surfaces as basic objects, holography, effective 2-dimensionality, are some of the terms appearing repeatedly in the article. The model contains some unacceptable features such as Planck length as minimal wave length in obvious conflict with Lorentz invariance.

Towards the end of year 2015 I rewrote the article since I realized that the diffraction analog serving as the starting point in Hogan's model cannot be justified in TGD framework. Fortunately, diffraction can be replaced by diffusion emerging very naturally in TGD framework and finally allowing to understand how Planck length emerges from TGD framework, where CP_2 size is the fundamental length parameter.

8.1 The Experiment

Consider first the graviton detector used in GEO600 experiment. The detector consists of two long arms (the length is 600 meters)- essentially rulers of equal length. The incoming gravitational wave causes a periodic stretch of the arms: the lengths of the rulers vary. The detection of gravitons means that laser beam is used to keep record about the varying length difference. This is achieved by splitting the laser beam into two pieces using a beam splitter. After this the beams travel through the arms and bounce back to interfere in the detector. Interference pattern tells whether the beam spent slightly different times in the arms due to the stretching of arm caused by the incoming gravitational radiation. The problem of experimenters has been the presence of an unidentified noise in the range 100-1500 Hz.

The prediction of the article *Measurement of quantum fluctuations in geometry* by Craig Hogan [E10] is that holographic geometry of space-time should induce fluctuations of classical geometry with a spectrum which is completely fixed. Hogan's prediction is very general and - if I have understood correctly - the fluctuations depend only on the duration (or length) of the laser beam using Planck length as a unit. Note that there is no dependence on the length of the arms and the fluctuations characterize only the laser beam. Although Planck length appears in the formula, the fluctuations need not have anything to with gravitons but could be due to the failure of the classical description of laser beams. The great surprise was that the prediction of Hogan for the noise is of the same order of magnitude as the unidentified noise bothering experiments in the range 100-700 Hz.

In the following I will discuss Hogan's model and consider two alternative TGD based explanations for the observations (assuming that they are real).

8.2 Hogan's Theory

Let us try to understand Hogan's theory in more detail.

1. The basic quantitative prediction of the theory is very simple. The spectral density of the noise for high frequencies is given by $h_H = t_P^{1/2}$, where $t_P = (\hbar G)^{1/2}$ is Planck time. For low frequencies h_H is proportional to 1/f just like 1/f noise. The power density of the noise is given by t_P and a connection with poorly understood 1/f noise appearing in electronic and other systems is suggestive. The prediction depends only Planck scale so that it should very easy to kill the model if one is able to reduce the noise from other sources below the critical level $t_P^{1/2}$. The model predicts also the distribution characterizing the uncertainty in the direction of arrival for photon in terms of the ratio l_P/L. Here L is the length or beam of equivalently its duration. A further prediction is that the minimal uncertainty in the arrival time of photons is given by $\Delta t = (t_P t)^{1/2}$ and increases with the duration of the beam.

2. Both quantum and classical mechanisms are discussed as an explanation of the noise. Gravitational holography is the key assumption behind both models. Gravitational holography states that space-time geometry has two space-time dimensions instead of three at the fundamental level and that third dimension emerges via holography. A further assumption is that light-like (null) 3-surfaces are the fundamental objects.

8.2.1 Heuristic argument

The model starts from an optics inspired heuristic argument.

1. Consider a light ray with length L, which ends to aperture of size D. This gives rise to a diffraction spot of size $R = \lambda L/D$. The resulting uncertainty of the transverse position of source is minimized when the size of diffraction spot is same as aperture size: $R = D$. This gives for the transverse uncertainty of the position of source $\Delta x = R = D = (\lambda L)^{1/2}$. The orientation of the ray can be determined with a precision $\Delta\theta = (\lambda/L)^{1/2}$. The shorter the wavelength the better the precision. Planck length is believed to pose a fundamental limit to the precision. The conjecture is that the transverse indeterminacy of Planck wave length quantum paths corresponds to the quantum indeterminacy of the metric itself. What this means is not quite clear to me.

2. The basic outcome of the model is that the uncertainty for the arrival times of the photons after reflection is proportional to

$$\Delta t = t_P^{1/2} \times (sin(\theta))^{1/2} \times sin(2\theta) \ ,$$

   where θ denotes the angle of incidence on beam splitter. In normal direction Δt vanishes. The proposed interpretation is in terms of Brownian motion for the distance between beam splitter and detector the interpretation being that each reflection from beam splitter adds uncertainty. This is essentially due to the replacement of light-like surface with a new one orthogonal to it inducing a measurement of distance between detector and bean splitter.

This argument has some aspects which I find questionable.

1. The assumption of Planck wave length waves is certainly questionable. The underlying assumption is that it leads to the classical formula involving the aperture size which is eliminated from the basic formula by requiring optimal angular resolution. One might argue that a special status of waves with Planck wave length breaks Lorentz invariance but since the experimental apparatus defines a preferred coordinate system this ned not be a problem.

2. Unless one is ready to forget the argument leading to the formula for $\Delta\theta$, one can argue that the description of the holographic interaction between distant points induced by these Planck wave length waves in terms of aperture with size $D = (l_P L)^{1/2}$ (of order proton Compton length for $L = 10^4$ meters) should have some more abstract physical counterpart.

   Could elementary particles as extended 2-D objects (as in TGD) play the role of ideal apertures to which a radiation with Planck wave length arrives? In this case L would be optimized. If one gives up the assumption about Planck wave radiation the uncertainty increases as λ. To my opinion one should be able to deduce the basic formula without this kind of argument.

   Could Planck length correspond ib TGD framework to the uncertainty for the position of the fermion lines associated with the generalized Feynmann graphs defined by light-like orbits of wormhole throats?

8.2.2 Argument based on Uncertainty Principle for waves with Planck wave length

Second argument can do without diffraction but still uses the highly questionable Planck wave length waves.

1. The interactions of Planck wave length radiation at null surface at two different times corresponding to normal coordinates z_1 and z_2 at these times are considered. From the standard uncertainty relation between momentum and position of the incoming particle one deduces uncertainty relation for transverse position operators $x(z_i)$, i=1, 2. The uncertainty comes from uncertainty of $x(z_2)$ induced by uncertainty of the transverse momentum $p_x(z_i)$. The uncertainty relation is deduced by assuming that $(x(z_2) - x(z_1)/(z_2 - z_1)$ is the ratio of transversal and longitudinal wave vectors. This relates $x(z_2)$ to $p_x(z_i)$ and the uncertainty relation can be deduced. The uncertainty increases linearly with $z_2 - z_1$. Geometric optics is used to describe the propagation between the two points and this should certainly work for a situation in which wavelength is Planck wavelength if the notion of Planck wave length wave makes sense. From this formula the basic predictions follow.

2. Hogan emphasizes that the basic result is obtained also classically by assuming that light-like surfaces describing the propagation of light between ends points of arm describe Brownian like random walk in directions transverse to the direction of propagation. Does this mean that Planck wave length wave is not absolutely necessary for this approach.

I admit that I find it difficult to follow the arguments.

8.2.3 Description in terms of equivalent gravitonic wave packet

Hogan discusses also an effective description of holographic noise in terms of gravitational wave packet passign through the system.

1. The holographic noise at frequency f has equivalent description in terms of a gravitational wave packet of frequency f and duration $T = 1/f$ passing through the system. In this description the variance for the length difference of arms using standard formula for gravitational wave packet is given by

$$\frac{\Delta l^2}{l^2} = h^2 f \quad ,$$

   where h characterizes the spectral density of the gravitational wave. This is extremely small number requiring l to be macroscopic length so that amplification from Planck lengths takes place.

2. For high frequencies one obtains

$$h = h_P = (t_P)^{1/2} \quad .$$

3. For low frequencies the model predicts

$$h = \frac{f_{res}}{f}(t_P)^{1/2}.$$

   Here f_{res} characterized the inverse residence time in detector and is estimated to be about 700 Hz in GEO600 experiment.

4. The predictions of the theory are compared to the unidentified noise in the frequency range 100-600 Hz which introduces amplifying factor varying from 7 to 1. The orders of magnitude are same.

8.3 TGD Based Model

Planck length as a minimal wavelength is in sharp conflict with Lorentz invariance. This is the fatal failure of the model for the claimed noise relying on diffraction as analog phenomenon. TGD approach suggests that diffusion in degrees of freedom transversal to light-orbits of partonic 2-surfaces representing particle orbits is a more promising analogy to start with.

8.3.1 Some background

Consider first the general picture behind the TGD inspired model.

1. What authors emphasize can be condensed to the following statement: *The transverse indeterminacy of Planck wave length seems likely to be a feature of 3+1 D space-time emerge is as a dual of quantum theory on a 2+1-D null surface.* In TGD light-like 3-surfaces indeed are the fundamental objects and 4-D space-time surface is in a holographic relation to these light-like 3-surfaces. The analog of conformal invariance in light-like radial direction implies that partonic 2-surfaces are actually basic objects in short scales in the sense that one 3-dimensionality only in discretized sense.

2. Both the interpretation as almost topological quantum field theory, the notion of finite measurement resolution, number theoretical universality making possible p-adicization of quantum TGD, and the notion of quantum criticality lead to a fundamental description in terms of discrete points sets. These are defined as intersections of what I call number theoretic braids with partonic 2-surfaces X^2 at the boundaries of causal diamonds identified as intersections of future and paste directed light-cones forming a fractal hierarchy. These 2-surfaces X^2 correspond to the ends of light-like three surfaces. Only the data from this discrete point set is used in the definition of M-matrix: there is however continuum of selections of this data set corresponding to different directions of light-like ray at the boundary of light-cone, and in detection one of these direction is selected and corresponds to the direction of beam in the recent case.

3. Fermions correspond to CP_2 type vacuum extremal with Euclidian signature of induced metric condensed to space-time sheet with Minkowskian signature and light-like wormhole throat for which 4-metric is degenerate carries the quantum numbers. Bosons correspond to wormhole contacts consisting of a piece of CP_2 vacuum extremal connecting two two space-time sheets with Minkowskian signature of induced metric. The strands of number theoretic braids carry fermionic quantum numbers and discretization is interpreted as a space-time correlate for the finite measurement resolution implying the effective grainy nature of 2-surfaces.

8.3.2 How to end up with TGD inspired model?

TGD does not seem to provide a justification for the models based on diffraction as physical phenomenon behind the noise.

1. Could one assign Planck wave length with the light-like orbit of partonic 2-surface involving periodic variation of CP_2 coordinates characerized by Planck length? Here the problem is that CP_2 length which is 10^4 times longer seems more natural guess for the minimum wavelength in this sense. For shorter wavelengths induced metric changes signature as simple ansatz shows.

2. Planck wave length as minimum wavelength means breaking of Lorentz invariance. Generalized Feynman diagrams correspond to space-time regions with Euclidian signature of induced metric- wormhole contacts typically. Elementary particles correspond to pairs of wormhole contacts. Could one assign the Planck length as wavelength to a periodic variation of angle-like CP_2 coordinate inside wormhole contact? One would could avoid problems with Lorentz invariance and maybe the diffraction picture would make sense inside Euclidian regions. The problem is that wave motion is impossible in Euclidian signature.

3. Could Planck length correspond to the position uncertainty section of so called massless extremals (MEs) assignable to MEs and orthogonal to the direction of propagation. Or could one interpret Planck length as uncertainty for the transverse position of the fermionic lines entering the diffraction slit? This however forces to give up the diffraction picture and formulas become just dimensional arguments.

Could diffusion replace diffraction as starting point?

1. Could one begin directly from the formula $\Delta x = R = D = \sqrt{l_P L}$. This would allow also to avoid problems with Lorentz invariance coming from the idea of minimum wavelength. One would give up the interpretation of l_P as wavelength so that the formula would be just dimension analytic guess and therefore unsatisfactory.

2. Could one assign Δx to the randomness of the light-like orbit of wormhole contact/partonic 2-surface/fermionic line at it. Δx would represent the randomness of the transversal coordinate for light-like parton orbit. This randomness could be also assigned to the light-like curves defining fermion lines at the orbits of partonic 2-surfaces. Diffusion would provide the physical analogy rather than diffraction.

   $T = L/c$ would correspond to time and $\Delta x = R = D$ would be analogous to the mean square distance $\langle r^2\rangle = DT$. $D = c^2 t_P$, diffused during time T. This would also conform qualitatively with the basic idea of p-adic thermodynamics. One would also find the long sought interpretation of Planck length in TGD framework where CP_2 length scale is the fundamental length scale.

3. Why the noise would appear at certain frequency range? A possible explanation is that large Planck constants are involved. The ratios of the frequency f_h of laser beam to the relatively low frequencies f_l in the frequency range of noise corresponds to the spectrum of Planck constants $h_{eff} = f_h/f_l$ involved? Maybe low frequencies could correspond to bunches of dark low energy photons with total energy equal to that of laser photon. Dark photons could relate to the long range correlations inside laser beam.

   The presence of large values of Planck constants suggests strongly quantum criticality, which should relate to laser beam. Could one assign the long range correlations of laser beam with quantum criticality realized as spectrum of Planck constants?

8.3.3 Large h_{eff} gravitons do not explain the claimed anomaly

In [K26] I have proposed that part of gravitons could arrive as large h_{eff} gravitons having same frequency as ordinary gravitons but by a factor h_{eff}/h higher energy, and thus have much larger effect than ordinary gravitons. They could transfrom with some probability to ordinary very high energy gravitons or decay to a bunch of $h_{eff}/h = n$ ordinary gravitons with the same frequency.

The additional assumption is $\hbar_{eff} = \hbar_{gr} = GMm/v_0$, where M is mass of the source of gravitations, m the mass of the receiver particle (elementary particle, most naturally proton), and v_0 is some characteristic velocity parameter associated with the source, characterizes the Kähler magnetic flux tubes along which dark gravitons arrive.

Dark gravitons could be detected in two ways. They could transform to ordinary gravitons but with much larger energy and absorbed by oscillator like system. This detection mechanism would be purely quantal. If the value of h_{gr} is of same order of magnitude as the model for bio-photons as decay products of dark photons suggests, the energy of "bio-graviton" would be in range of visible and UV energies. Bio-.gravitons could be important in living matter.

Second option is that dark graviton decays to a bunch of h_{eff}/h ordinary gravitons, which because of their large number define a semiclassical state (large n limit for a harmonic oscillator corresponds to quasiclassical state). In semiclassical approximation one would have a classical gravitational wave with amplitude defined by oscillator state containing $n = h_{eff}/h = GMm/v_0\hbar$ gravitons. Since n is large, the oscillator state allows an approximation as classical gravitational wave with amplitude scaled up by $\sqrt{n}$ from its value for ordinary value of Planck constant. The amplitude would be by a factor $\sqrt{GMm/v_0\hbar}$ for the oscillation amplitude of distance between the ends of the arm of the detector would scale up by a factor $\sqrt{Gmm/v_0\hbar}$, which is of order 10^{11} for M of order solar mass, m proton mass and $v_0/c \simeq 10^{-3}$. If the amplitude for oscillation of distance between ends of arm is about 10^{-17} meters, it would be amplified to cell scale 10^{-6} meters, perhaps not an accident.

This kind of bunches of ordinary gravitons would be interpreted as noise in GRT framework. The noise in above sense cannot correspond to dark gravitons.

8.4 Hogan's Formula Again

My interest to the claimed unidentified noise modelled by Hogan was re-stimulated eight years later as Bee (see `http://tinyurl.com/y8fm8d6f`) told in rather critical tone about an article titled "Search for Space-Time Correlations from the Planck Scale with the Fermilab Holometer" reporting the results of Fermilab experiment (see `http://tinyurl.com/y8btj956`) [E25].

The claim of Craig Hogan, who leads the experimental group, is that the experiment is able to demonstrate the absence of quantum gravity effects. The claim is based on a dimensional estimate for transversal fluctuations of distances between mirrors reflecting light - it seems to be essentially the same as discussed in detail above. The fluctuations of the distances between mirrors would be visible as a variation of interference pattern and the correlations of fluctuations between distant mirrors could be interpreted as correlations forced by gravitational holography. No correlations were detected and the brave conclusion was that predicted quantum gravitational effects are absent.

Although no quantitative theory for the effect exists, the effect is expected to be extremely small and non-detectable by quantum holographists. Hogan has however different opinion based on his view about gravitational holography not shared by workers in the field (such as Lenny Susskind). This of course need not mean that his formulate might not be correct!

One has volume size R and the area of of its surface gives bound on entanglement entropy implying that fluctuations must be correlated. A very naïve dimensional order of magnitude estimate would suggest that the transversal fluctuation of distance between mirrors (due to the fluctuations of space-time metric) would be given by $\langle \Delta x^2 \rangle \sim (R/l_P) \times l_P^2$. For macroscopic R this could be measurable number. In the above application R becomes the length of the laser beam. This estimate is of course ad hoc, involves very special view about holography, and also Planck length scale mysticism is involved. There is no theory behind it as Bee correctly emphasizes. Therefore the correct conclusion of the experiments would have been that the formula used is very probably wrong.

8.4.1 How the view of Hogan about holography is wrong?

Why I saw the trouble of writing comments about this was that I want to try to understand what is involved and maybe make some progress in understanding TGD based holography to the GRT inspired holography. The somewhat polarized comment went as follows.

1. The argument of Hogan involves an assumption, which seems to be made routinely by quantum holographists: the 2-D surface involved with holography is *outer* boundary of macroscopic system and bulk corresponds to its interior. This would make the correlation effect large for large R if one takes seriously the dimensional estimate large for large R. The special role of outer boundaries is natural in AdS/CFT framework. In the actual situation however R is replaced with the length of beam so that the situation need not have much to do with holography.

2. In TGD framework outer boundaries do not have any special role. For strong form of holography (SH) the surfaces involved are string world sheets and partonic 2-surfaces serving as "genes" from which one can construct space-time surfaces as preferred extremals by using infinite number of conditions implying vanishing of classical Noether charges for sub-algebra of super-symplectic algebra.

   For weak form of holography one would have 3-surfaces defined by the light-like orbits or partonic 2-surfaces: at these 3-surfaces the signature of the induced metric changes from Minkowskian to Euclidian and they have partonic 2-surfaces as their ends at the light-like boundaries of causal diamonds (CDs). For SH one has at the boundary of CD fermionic strings and partonic 2-surfaces. Strings serve as geometric correlates for entanglement and SH suggests a map between geometric parameters - say string length - and information theoretic parameters such as entanglement entropy.

3. The typical size of the partonic 2-surfaces is CP_2 scale about 10^4 Planck lengths for the ordinary value of Planck constant. The naïve scaling law for the the area of partonic 2-surfaces would be $A \propto h_{eff}^2$, $h_{eff} = n \times h$. An alternative form of the scaling law would be as $A \propto h_{eff}$. CD size scale T would scale as h_{eff} and p-adic length scale as its square

root (diffused distance R satisfies $R \sim L_p \propto T^{1/2}$ in diffusion; p-adic length scale would be analogous to R).

4. The most natural identification of entanglement entropy would be as entanglement entropy assignable with the *union* of partonic 2-surfaces for which the light-like 3-surface representing generalized Feynman diagram is connected. Entanglement would be between ends of strings beginning from different partonic 2-surfaces. There is *no* bound on the entanglement entropy associated with a given Minkowski 3-volume coming from the area of its *outer* boundary since interior can contain very large number of partonic 2-surfaces contributing to the area and thus entropy. As a consequence, the correlations between fluctuations are expected to be weak.

5. Just for fun one can feed numbers into the proposed dimensional estimate, which of course does not make sense now. For R about of order CP_2 size it would predict completely negligible effect for ordinary value of Planck constant: this entropy could be interpreted as entropy assignable to single partonic 2-surface. Same is true if R corresponds to Compton scale of elementary particle.

This argument demonstrates how sensitive the quantitative estimates are for the detailed view about what holography really means. Loose enough definition of holography can produce endless number of non-sense formulas and it is quite possible that AdS/CFT modelled holography in GRT is completely wrong.

The difference between TGD based and GRT inspired holographies is forced by the new view about space-time allowing also Euclidian space-time regions and from new new view about General Coordinate Invariance implying SH. This brings in a natural identification of the 2-surfaces serving as holograms. In GRT framework these surfaces are identified in ad hoc manner as outer surfaces of arbtrarily chosen 3-volume.

8.4.2 Why the formula used by Hogan could be partially correct after all?

After I had went through the earlier model for the claimed noise and modified it in some respects, I had still unpleasant feeling that I have not understood everything. TGD predicts the noise and it could be called quantum gravitational. The earlier experiment provides a support for its existence but the recent experiment does not.

How does the earlier experiment reporting unidentified fluctuations and interpreted in the proposed manner in TGD framework relate to the recent experimental finding reporting no fluctuations? I am not experimentalists but the experimental situations look very much the same.

The simplest explanation emerging from quantum criticality in TGD sense is that the frequency range studied in Fermilab experiment does not correspond to the frequencies made possible by the available spectrum of Planck constants. If I have understood correctly, the range corresponds to considerably higher frequencies than the range 300-1500 Hz for the noise detected in the original experiments.

I do not know whether people have been able to eliminate the noise reported in the motivating article [E38]. I hope not! It is unclear whether how the model relates to the Hogan's later model proposing that the correlations implied by holography as he interprets it, are not found. Certainly the idea that Planck wave length waves would be amplified to observable noise does not make sense in TGD framework. It is diffusion of fermion lines in transversal degrees of freedom of light-like random orbits of partonic 2-surfaces serving as a signature of non-point-likeness of fundamental objects, which would become visible as noise. The effect could also seem as signature for the hierarchy of Planck constants and also to quantum gravitational holography.

9 Could Hyperbolic 3-Manifolds And Hyperbolic Lattices Be Relevant In Zero Energy Ontology?

In zero energy ontology (ZEO) lattices in the 3-D hyperbolic manifold defined by H^3 ($t^2 - x^2 - y^2 - z^2 = a^2$) (and known as hyperbolic space to distinguish it from other hyperbolicmanifolds (see `http://tinyurl.com/yct48tv6`) [A3]) emerge naturally. The interpretation of H^3 as a cosmic time=constant slice of space-time of sub-critical Robertson-Walker cosmology (giving future light-cone of M^4 at the limit of vanishing mass density) is relevant now.

9.1 Hyperbolic Lattices In H^3 From Zero Energy Ontology

In TGD framework zero energy ontology (ZEO) indeed predicts the hyperbolic lattices if one accepts the following argument.

1. Causal diamond CD is basic element of ZEO. It is defined as the intersection of a pair of future and past directed light-cones and looks like double pyramid Cartesian product with CP_2 makes it 8-D region off $M^4 \times CP_2$ but the presence of CP_2 as Cartesian factor is not relevant. Its opposite light-like boundaries contain positive and negative energy parts of zero energy states with opposite total quantum numbers. In the usual positive energy ontology zero energy states corresponds to physical events consisting of initial and final states. ZEO is consistent with the crossing symmetry of QFTs. ZEO leads to a generalization of S-matrix concept. The time-like entanglement coefficients between positive and negative energy parts of zero energy state define M-matrix identifiable as a "complex square root" of density matrix and expressible as a product of Hermitian square root of density matrix and unitary S-matrix. One can say that quantum theory corresponds to a square root of thermodynamics in ZEO.

2. The "lower" tip of CD can have any position in M^4: one can argue that these degrees of freedom give rise to 4-momentum. The "upper" tip is at M^4 proper time distance a assumed to be integer multiple of CP_2 size. The assumption motivated by number theoretical considerations (the goal is to fuse real and p-adic physics and real continuum must be effectively replaced by rationals or at most their algebraic extension). One can of course consider also the discretization for the position of the lower tip in M^4 and interpret it in terms of finite measurement resolution for four-momentum.

3. One can perform for CD Lorentz boosts preserving the fixed position of "lower" tip but one cannot allow all possible transformations since one would have two separate 3-D continuous degrees of freedom in this case (here is the crux of argument). Therefore I assume that "upper" tip which lies on the hyperbolic space H^3 - hyperboloid - defined by $t^2-x^2-y^2-z^2=a^2$, $a=n$ in proper units defined by the size scale of CP_2, can have only discrete positions corresponding to a discrete subgroup G of $SL(2,C)$ (double covering of Lorentz group). Recall that H^3 has negative constant sectional curvature.

4. The discrete subgroup G defining G-coset as points of H^3/G is in the most general case discrete subgroup of $SL(2,C)$. It could be also modular subgroup $SL(2,Z)$ or its. Quite generally, one obtains a tessellation of H^3 with a lattice characterizing positions of unit cells H^3/G, which are closed hyperbolic manifolds in absence of singular points known as cusp points and giving rise to punctures and effectively holes. Physically unit cell or fundamental domain corresponds to an open set and effective identification of boundary points comes through "G-periodic" boundary conditions for physical fields analogous to periodic boundary conditions in the case of condensed matter physics. H^3/G has constant negative curvature metric.

9.1.1 Some examples of hyperbolic manifolds

In order to make things more concrete it is good to have some examples about hyperbolic manifolds.

1. Examples about hyperbolic manifolds are provided by compactifications of tetrahedron and dodecahedron. It is possible to remove the vertices of tetrahedron and identify the faces of tetrahedron in a pairwise manner to get a compact manifold with boundary having the topology of Klein bottle (non-orientable torus). This manifold is known as Gieseking manifold (see `http://tinyurl.com/y9elobcs`) [A2]. This space has finite volume, is non-orientable, and the boundary corresponds to the cusp. Gieseking manifold is a double cover of the knot complement of figure eight knot which explains why the boundary has genus $g=1$.

2. The so called Seifert-Weber space (see `http://tinyurl.com/ya249rkf`) [A12] is a closed hyperbolic manifold obtained by gluing each face of a dodecahedron with its opposite. So called Weeks manifold (see `http://tinyurl.com/yd8e5ysz`) [A17] has smallest volume among closed hyperbolic 3-manifolds. If the volume of the hyperbolic manifolds surfaces as the analog of energy in topological thermodynamics, Weeks manifold might be one of the favored 3-manifold topologies.

3. Thurston's geometrization conjecture (see `http://tinyurl.com/yb2jlcca`) [A15] (actually a theorem thanks to the work of Grigori Perelman) implies that all knot complements except those of satellite knots (they include composites of prime knots and torus knots!) and torus knots (trefoil is the simplest example) are hyperbolic manifolds.

4. Kleinian groups (see `http://tinyurl.com/melaebe`) [A6] identified as a discrete subgroups G of $PSL(2C)$ acting as isometries of H^3 and conformal symmetries of Riemannian sphere (Möbius transformations) define hyperbolic manifolds as quotients H^3/G. The fundamental group of any hyperbolic manifold is Kleinian group acting also as group of symmetries of a tessellation of H^3.

9.1.2 Questions

Could hyperbolic lattices and crystals and hyperbolic manifolds have some physical role in TGD?

1. The points of hyperbolic lattices could label astrophysical (possibly dark matter) objects. The indications for the existence of astrophysical objects at lines of sight and coming with quantized redshift [E33, E43] supports this picture [K31]. In cosmology redshift for small distances r is from Hubble law given by $v = Hr$ so that the recession velocity - or equivalently cosmic redshift - serves as a natural measure for the distance.

   If dark matter objects corresponds to CDs with upper vertices at the points of H^3/G, both the directions and magnitudes of the recession velocities would be quantized. The quantization for the velocities would follow from the quantization of the hyperbolic angle η defining Lorentz boosts as integer multiples of basic value: $\eta = n\eta_0$ giving $v/\sqrt{1-v^2} = sinh(\eta) = sinh(n\eta_0)$ ($c = 1$) reducing for non-relativistic velocities to $v \simeq n\eta_0$.

2. 3-surface is a fundamental dynamical object in TGD. Hyperbolic 3-manifolds are central in the theory of 3-manifolds, and very many 3-manifolds are hyperbolic. Note that also 2-D manifolds with $g > 1$ are hyperbolic. For instance, knot complements of prime knots are hyperbolic apart from some exceptions, and also surface bundles over circle (see `http://tinyurl.com/y7mqceqc`) [A14] are hyperbolic. Thurston's theorem (see `http://tinyurl.com/y9hv3y9h`) [A16] states that the volume of the hyperbolic manifold defines a topological invariant so that continuous deformations of 3-surfaces would correspond to the same hyperbolic volume, which could thus appear as a counterpart of energy in topological thermodynamics telling which hyperbolic 3-manifold topologies contribute significantly to the physical states (in ZEO this thermodynamics is replaced with its "square root").

3. In TGD framework elementary particles correspond to closed flux tube like structures carrying monopole flux. The solutions of the Kähler-Dirac equation [K40] assign to them closed stringy curves, which can get knotted (see `http://tinyurl.com/y7kb7mvl`) [K17] and in general case when several flux tubes are associated with the elementary particle (say in case of boson) even braiding becomes possible. The homological non-triviality of the knot brings in additional quantum numbers.

   It is natural to assign to the flux tube the geometry $X^2 \times S^1$ corresponding to trivial surface bundle over sphere. The two wormhole contacts associated with the ends of the flux tube allow gluing of X^2 from upper space-time sheet with that associated with the lower space-time sheet and this would transform $X^2 \times S^1$ to a non-trivial bundle. Hence the topology of the flux tube could be characterized by hyperbolic volume. The induced metric of course need not be hyperbolic metric.

4. What is interesting that the isometry group of H^3 has $SL(2,C)$ as a double covering and H^2 realized as upper half-plane has $SL(2,C)$ as conformal isometries. Could this mean some

kind of duality analogous to AdS-CFT duality? The hyperbolic manifolds H^3/G have 2-D boundary: could there be a duality between 2-D conformal field theory at the boundary and string theory in the interior. This is suggested by the strong form of holography (equivalently strong form of general coordinate invariance) stating that partonic 2-surfaces and their 4-D tangent space data code for quantum physics in TGD Universe.

This raises several questions.

1. What happens to 3-D Euclidian crystallography when E^3 is replaced with H^3? How the negative constant sectional curvature affects the character of lattices obtained?

2. Can one build a rough overview about hyperbolic manifolds? Under what conditions the fundamental domain regarded as an open manifold analogous to lattice cell can be compactified by G-periodic boundary conditions to a closed 3-manifold? To me this is not obvious since the compactified manifold could have singularities known as cusps points and represent punctures.

3. Does one obtain also hyperbolic quasicrystals? One can imagine also 2-D hyperbolic quasicrystals analogous to Penrose tilings (see `http://tinyurl.com/y8cddhz6`) [A9] defined by the embedding of 2-D hyperbolic manifold H^2 to H^3 (or higher dimensional hyperbolic space) and by projecting the points of H^3 to H^2 along geodesic lines orthogonal to H^3. One can also imagine 3-D hyperbolic quasicrystals as analogs of Penrose tilings obtained by embedding H^3 to H^4 or H^5 and performing similar projection.

It turns out that a visit to Wikipedia allows to answer the first two questions.

9.2 Comparing Crystallographies in E^3 and H^3

Consider first crystallography in E^3. There exists a large number of lattice like structures depending on detailed definition used and it is good to summarized first the basic notions.

9.2.1 Some definitions

Consider first some basic notions.

1. The difference between crystal and lattice is that crystal structure assigns to a given point of lattice some structure, which can be rather complex. In the simplest case this structure is a Platonic solid - a polyhedron which can be regarded as an orbit of a discrete group generated by reflections and rotations.

2. Lattice (see `http://tinyurl.com/vtkbd`) [A1] in 3-D case can be defined group theoretically in terms of the group leaving the lattice invariant. This group - call it G - is generated by the elements of two groups, the crystallographic point group (see `http://tinyurl.com/l3f9a37`) [A10] and space-group (see `http://tinyurl.com/ox9sn66`) [A13].

   Point group leaves at least single point of the lattice fixed and defines the symmetries of the structure attached to the lattice point identified as the center point of the structure. There are 32 point groups and they contain reflections across plane, rotations, inversions (3-D reflecting with respect to origin), and improper rotations (rotations followed by inversion).

   Space group contains pure translations, screw transformations rotating around axing and translating along it, and gliding transformation consistent of reflection with respect to plane followed by a translation. There are 230 distinct space groups. The lattice is defined as the set of cosets E^3/G, where G is so called space-group leaving the lattice invariant.

3. The lattice points are in the general case linear combinations of three - in general non-orthogonal - basis vectors (a, b, c) generating the discrete subgroup of translations. The condition that one has crystal consisting of say tetrahedrons as unit cells - poses additional conditions. The duals of the lattice vectors defined by their cross products generate dual lattice.

9.2.2 Tessellations

Tessellation or tiling is second key notion and there are many different variants of this notion. The most stringent definition of tessellations considered in following is in terms of by a $n+1$-dimensional regular polytope in n-dimensional sphere, Euclidian space, or hyperbolic space.

1. Polytopes are constructed of regular p-polygons in turn defining the 2-D faces of 3-D polyhedrons in defining the 4-D polychrones.

2. n-dimensional tessellations can be defined as boundaries of $n+1$-dimensional polygons. Schläfli symbol (see `http://tinyurl.com/5vbt6tx`) [A11] allows to represent n-dimensional tessellations in terms of integer n-tuple of integers. In 3-D case one has triple (p, k, r). p is the number of vertices of 2-polygon defining the face of 3-D polyhedron (p, k) and k is the number of faces associated with a given vertex of the polyhedron. r is the number of 3-D polyhedra associated with a given edge of the tessellation.

3. In the case of 2-sphere tessellation in E^3 contains finite number of identical faces projected to the sphere. tessellations can make sense also if the n-D space is non-compact and the replacement of sphere S^3 of E^4 with hyperbolic space H^3 gives rise to infinite tessellation of H^3. Also tessellations in hyperbolic manifolds H^3/G are possible and in closed case contain a finite number of basic elements.

   tessellations by regular polytopes (see `http://tinyurl.com/dxmjm7r`) [A7] satisfy strong constraints and there are only four tessellations by regular polytopes in H^3 and one in E^3.The list of tessellations is following.

   (a) E^2 allows three regular tessellations by squares, triangles and hexagons: the Schäfli symbols for them are (4, 4), (3, 6), (6, 3).

   (b) H^2 is exceptional and allows infinite number of tessellations.

   (c) E^3 allows single tessellation by cubes: the Schläfli symbol is $(4, 3, 4)$.

   (d) H^3 allows four tessellations. The Schläfli symbols are (3, 5, 3), (4, 3, 5), (5, 3, 4), (5, 3, 5). Second and third tessellation are dual tessellations by cubes and dodecahedra. First and fourth tessellation correspond to self-dual tessellations by icosahedra and dodecadedra. For instance, for (5, 3, 5) means each edge has 5 dodecahedrons around it.

   The large voids with size of order 10^8 ly give rise to honeycomb like structures. Could they correspond to ordinary matter condensed around dark matter honeycomb consisting of dodecahedra?

   (e) For $n > 4$ there are three regular tessellations by convex polyhedra in Euclidian space. There are no regular hyperbolic tessellations by convex polyhedra in dimensions $n > 5$.

4. If an infinite n-D tessellation is induced by $n+1$-D regular polytope, it seems obvious that the polygon must have infinite number of basic units. There indeed exists this kind of infinite polytopes known as infinite skew polytopes (see `http://tinyurl.com/y7q4bxu9`) [A5]. 1-D lattice requires 2-D zigzag curve reflected from the real axis at the lattice points. In 1-D cases zigzag curve actually gives two parallel lines carrying lattices and the parallel lines together define a boundary of a stripe. Similar doubling is expected in higher dimensions since it is the boundaries of polytopes, which must give rise to H^n or E^n.

5. The tessellations having E^3/G as a unit cell are obtained by assuming G to be a subgroup of translations. As already noticed this subgroup in question is generated by 3 generators represented by - in general non-orthogonal vectors - and the fundamental domain is parallelpiped generated by these vectors. When the vectors are orthogonal and have same length one obtains the regular tessellation by cubes. The four tessellations by regular polytopes must be distinguished from the infinite number of tessellations defined by the orbit of discrete subgroup $G \subset PSL(2, C)$ in H^3 with fundamental domain H^3/G replacing the polyhedron

as a basic unit. The case of E^3 suggests that these tessellations give as a special case the 4-tessellations using regular polytopes. A good first guess is that G is generated by Lorentz boosts with same velocity in 3 orthogonal directions.

9.2.3 Tessellations of H^3

Consider now the case of H^3 more closely.

1. In the case of H^3 a discrete subgroup G of Lorentz group $SL(2,C)$ with infinite number of elements representing Lorentz boots replaces discrete subgroup of translations in E^3. G is known as Kleinian group (see `http://tinyurl.com/melaebe`) [A6]. G can be also restricted to be a subgroup of the modular group $SL(2,Z)$. Note that $G = SL(2,Z)$ is braid group for 3-braid divided by its center and isomorphic to the knot group of trefoil as one learns from Wikipedia (see `http://tinyurl.com/yroeq5e`) [A8]. Therefore the subgroups of the knot group of trefoil are very interesting concerning lattices in H^3. The complement of trefoil and any torus knot however fails to defined hyperbolic 3-manifold. For larger subgroups of $SL(2,C)$ one obtains smaller fundamental domain and more lattice points.

2. For non-compact discrete subgroups of $SL(2,Z)$ (and also $SL(2,C)$!) the lattice consists in the language of cosmologist of locations of astrophysical objects (possibly consisting of dark matter) with quantized redshifts and direction angles. The counterparts of parallelepipeds are interiors of hyperbolic 3-manifolds and there are very many of them. For prime knot complements which very often are hyperbolic 3-manifolds, the boundary is torus and allows a constant sectional curvature metric with vanishing sectional curvature. This motivates the question whether $g > 1$ negative constant sectional curvature 2-surfaces could appear as boundaries of hyperbolic 3-manifolds.

3. It is not completely obvious how to define the edges and faces of hyperbolic polygons. Edges are naturally defined as geodesic lines but what about faces. In E^3 they are pieces of plane which are minimal surfaces but also geodesic sub-manifolds with vanishing second fundamental form meaning that all geodesics of these surfaces are also geodesics of E^3. Minimal 2-surfaces are by definition manifolds with a negative curvature and this seems to fit with the negative curvature property of H^3. H^3, E^3, and S^3 are very closely related (they define the 3 constant sectional curvature Robertson Walker cosmologies) In the case of S^3 spheres S^2 are geodesic sub-manifolds. In the similar manner H^2 defines a geodesic sub-manifold of H^3. If so, the faces would be 2-D hyperbolic manifolds with boundary, and having constant negative sectional curvature.

4. One can wonder what is the 4-D space used to define H^3 tessellations. Is it Minkowski space M^4 or is it H^4? The first problem is that tessellation is infinite. Second problem is that H^3 should but cannot play the same role as sphere S^2 in E^3. The problem is that H^3 can be thought of as having boundary at infinity, and therefore is not itself a boundary unlike S^2. It is the boundary property of S^2, which allows to assign Platonic solid with the vertices of tetrahedron at the surface of S^2.

   Infinite tessellation requires infinite polytope as already noticed. For $1-D$ tessellation one has zigzag curve in planar stripe, and one obtains two copies of the tessellation defining a boundary of 2-D stripe. Are the segments of zigzag curve replaced by a 4-D object having as boundary cube, icosahedron, or dodecahedron of H^3? Does the boundary property require that there are two lattices at hyperboloids $a = a_1$ and $a = a_2$ of M^4. These hyperboloids define a boundary and one can speak about the interior and boundary of 4-D polytope.

   An interesting question is how this relates to zero energy ontology, where CD plays a key role. Can one imagine that the pair of H^3: s is replaced with a pairs of hyperboloids with opposite time orientation so that their intersection consists of temporal mirror images of part of H^3 glued together along 2-sphere (this could be seen as a generalization of CD)? The boundaries of CD would correspond to the limiting case $a = 0$ for H^3 giving light-cone boundary for which radial coordinate does not contribute to metric so that metrically one has 2-D sphere (this makes possible huge extension of conformal invariance in TGD Universe). How could one define tessellations of light-cone boundary?

5. For Platonic solids boundary is always topologically a sphere. For prime knot complements the boundary is 2-torus $S^1 \times S^1$. What does this mean geometrically in the gluing of fundamental domains together? Also 2-surface bundles over spheres are hyperbolic manifolds and are obtained by identifying the ends of $X^2 \times D^1$ by a homeomorphism. The homotopy equivalence class of the map $X^2 \to X^2$ characterizes the bundle structure. In this case one should fill the twisted torus like surface by polygon lattice.

9.3 About uniform tessellations of hyperbolic, Euclidian, spherical spaces

It has become clear that 3-D hyperbolic tessellations are probably very important in the TGD framework. The 3-D hyperbolic space H^3 is realized as a mass shell or cosmic time constant hyperboloid and an interesting conjecture is that particles with a fixed value of mass squared are associated with the vertices of a hyperbolic tessellation. This would give rise to a quantization of momenta consistent with the number theoretic discretization. Hyperbolic tessellations could also appear in cosmological scales. So called icosa-tetrahedral tessellation seems to provide a model of genetic code and DNA and suggests that genetic code is not restricted in biology but universal and realized in all scales Euclidian.

Uniform tilings/tessellations/honeycombs can be identified by their vertex configuration given given a list $n_1.n_2.n_3...$ for the numbers n of of vertices of regular n-polygons associated with the vertex. Uniform tilings can be regular, meaning that they are both vertex- and edge-transitive. Quasi-regular tessellations are only vertex-transitive and semiregular tessellations are neither vertex- or face-transitive. Non-regular tessellations give for instance Archimedean solids obtained from Platonic solids by operations like truncation. In this case the vertices are obtained by symmetries from each other but not the faces, which need not be identical anymore.

There exists an extremely general construction of tessellation of hyperbolic, Euclidian, and spherical tessellations which works at least in 2- and 3-D cases known as Wyuthoff construction. In the 2-D case, this construction is based on the so-called Schwarz triangles associated with a fundamental region of tessellation in the 2-D case and so-called Goursat tetrahedrons in the 3-D case. A natural generalization is that in n-dimensional one has n-simplexes. One would have what topologists call triangulation, which is very special in the sense that it utilizes the symmetries of the tessellation. These very special simplices are also consistent with the number theoretical constraints in the the angles between n-1-faces corresponds to angles defined by the roots of unity.

In the 2-D case the angles between the edges of the fundamental triangle are rational multiples of π so that the cosines and sines of the angle are algebraic numbers, which are natural for a tessellation whose points in natural coordinates (momenta) have components which are numbers in an algebraic extension of rationals. In the 2-D case, the fundamental triangle is obtained by drawing from center points of the 2-D unit cell, say a regular polygon, connecting it to its vertices. In the 3-D case the same is done for the 3-D unit cells of the fundamental region. Note that the tessellation can have several different types of unit cells and this is indeed true the case for icosa-tetrahedral tessellations.

9.3.1 2-dimensional case

In the 2-D case the angles between the edges of the triangle are given as $(1/p, 1/r, 1/s)$- multiples of π. p, r, and s are the orders of discrete rotation groups assignable to the vertices. They are generated by the reflections s_i with respect to edges of the triangle in one-one-correspondence with opposite vertices. They satisfy the conditions $s_i^2 = 1$ as reflections and the reflections s_i. The reflections s_i and s_{i+j}, $j > 1$ commute and $s_i s_{i+1}$ generates a rotation with respect to the third vertex of the triangles with order determined by one of the numbers p, r, s. The conditions can be summed up to $s_i^2 = 1$ and $(s_i s_j)^{m_{ij}} = 1$ $m_{ij} = 2$ for $j \neq i \pm 1$ and $m_{ij} > 2$ for $j = i \pm 1$. The conditions can be expressed in a concise way by using Coxeter-Dynkin diagrams having 3 vertices connected by edges. For $s_{ij} = 2$ there is no edge and for $s_{ij} > 2$ there is an edge and a number telling the order of the cyclic group in question.

All these 3 spaces are constant curvature spaces with positive, vanishing or negative curvature, which is reflected as properties of the angle sum of the geodesic Scwartz triangle (note that these spaces also occur in cosmology). In the spherical case the sum is larger than π and one has

$1/p + 1/r + 1/s \geq 1$. In the Euclidian case the sum of the angles of the Schwarz triangle is π, which gives the condition $1/p + 1/r + 1/s = 1$. In the hyperbolic case the angle sum is smaller than π andone has $1/p + 1/r + 1/s \leq 1$. Note that in the hyperbolic plane the angles of infinitely sized Scwartz triangle can vanish (ideal triangle). For the 2-sphere these conditions give only Platonic solids as regular (vertex- and face-transitive) tessellation (no overlap between triangles). For the(plane) the non-compactness implies that the conditions are not so restrictive as for the sphere. The most symmetric tessellations are regular tessellations: they involve only one kind of polygon and are vertex-, edge-, and face-transitive. For the Euclidian plane there are regular tessellations by triangles, squares and hexagons. If one weakens the transitivity conditions to say vertex-transitivity, more tessellations are possible and involve different kinds of regular polygons.

The Wikipedia article about the uniform tilings of hyperbolic plane gives a good overall view of the uniform tessellations of hyperbolic plane. For the hyperbolic tessellations the conditions are the least restrictive. Intuitively this is due to the fact that the angle sum can be small and this allows small angles between edges and more degree of freedom at vertices. For a spherical tessellation the situation is just the opposite. Uniform tilings of hyperbolic plane H^2 are by definition vertex transitive and have a constant distance between neighboring vertices. This condition is physically natural and would correspond to mechanical equilibrium in which vertices are connected by springs of the same string tension. Each symmetry (p, r, s) allows 7 uniform tilings characterized by Wythoff symbol or Coxeter diagram. These tiling in general contain several kinds of geodesic polygons. Families with $r = 2$ (right triangle) contain hyperbolic regular tilings.

9.3.2 The 3-dimensional case

There is a Wikipedia article about the uniform tessellations/honeycombs, in the 3-D case, obtained by Wyuthoff construction, is a generalization from the 2-D case. Schwarz triangle is replaced with Goursat tetrahedron and reflections are now in tetrahedral faces opposite to the vertices of the tetrahedron so that there are 4 reflections si satisfying $s_i^2 = 1$ and $s_is_j)^{m_{ij}} = 1$, $m_{ij} = 2$ for $j \neq i \pm 1$. The cyclic subgroups act as rotations of faces meeting at the edges and the angles defining the cyclic groups are dihedral angles. There are 9 compact Coxeter groups, and they define uniform tessellations with a finite fundamental domain. What is interesting is that the cyclic subgroups involved do not have order larger than 5.

The conditions are expressible in terms of Coxeter-Dynkin diagram with 4 vertices. The 2-D conditions are satisfied for the Schwarz triangles defining the faces of the tetrahedron. Besides the angle parameters defining the triangular phases of the tetrahedron there are angle parameters defining the angles between the faces. All these angles are rational multiples of π and define subgroups of the symmetries of the tessellation. What is so beautiful is that the construction is generalized to higher dimensions and is recursive/hierarchical.

The hyperbolic character of the geometry allows Schwarz triangles and Goursat tetrahedra which in Euclidian case would not be possible due to the condition that the edges have the same length and faces have the same area.

9.3.3 Could hyperbolic, Euclidian, and spherical tessellations be realized in TGD space-time

An interesting question is whether the hyperbolic, Euclidian, and spherical tessellations could be realized in the TGD framework as induced 3-D geometry or rather, as slicing of space-time surface by time parameter such that each slice represents hyperbolic, Euclidian or spherical geometry locally allowing the tessellation.

Hyperbolic tessellations can be realized on the cosmic time constant hyperboloids and Euclidian tessellations on the Minkowski time constant hyperplanes of M^4 and possibly partially on 3-surfaces which have hyperbolic 3-space as M^4 projection.

The question boils down to a construction of a model of Robertson-Walker cosmology for which the induced metric of $a = constant$ 3-surface is that of H^3, E^3 or S^3 corresponding to the cosmologies with subcritical, critical and overcritical mass densities. The metric of H^3 is proportional to a^2 scale factor. The simplest ansatz is a geodesic circle at geodesic sphere $S^2 \subset CP_2$ with metric $ds^2 = -R^2d\theta^2 - sin^2(\theta)d\Phi^2$. The ansatz $(sin(\theta) = a/a_0, \Phi = f(r))$ gives in Robertson-Walker coordintes the induced metric

$$ds^2 = [1 - R^2(\frac{d\theta}{da})^2]da^2 - a^2(\frac{1}{1+r^2} + (\frac{R}{a_0})^2(\frac{df}{dr})^2)dr^2 + r^2 d\Omega^2) \ .$$

This gives the flat metric of E^3 if the condition

$$(\frac{df}{dr})^2 = (\frac{a_0}{R})^2 \frac{r^2}{1+r^2} \ .$$

This condition is satisfied for all values of r.

For S^3 metric one obtains the condition

$$(\frac{df}{dr})^2 = (\frac{a_0}{R})^2 \frac{2r^2}{1-r^4} \ .$$

$r = 1$ corresponds to singularity. For $r = 1$, one has $r_M = ar = a$, which gives $t = \sqrt{2}a$. One can construct the S^3 by gluing together the hemispheres corresponding to the 2 roots for df/dr so that it seems that one obtains the tessellations. The divergence of df/dr tells that the half-spheres become orthogonal to H^3 at the gluing points.

For both E^3 and S^3 option, the component g_{aa} of the induced metric is equal to

$$g_{aa} = 1 - (\frac{R}{a_0})^2 \frac{1}{1 - (\frac{a}{a_0})^2} \ .$$

g_{aa} diverges at $a = a_0$ so that the cosmic time would run infinitely fast. g_{aa} changes sign for $a = a_0$ so that for $a > a_0$ the signature of the induced metric becomes Euclidian. Unless one allows Euclidian signature in long scales, one must assume $a < a_0$. Note that the action defined as the sum of Kähler action and volume action, If S^2 corresponds to the homologically trivially geodesic sphere of CP_2, the action reduces to volume action for these surfaces. The densities of Noether currents for volume action vanish at $a = a_0$ since they are proportional to the factor $\sqrt{g_{aa}}g^{aa}$ and thus approach to zero like $\sqrt{1-(a/a_0)^2}$. This is true also for the contribution of Kähler action present for homologically non-trivial geodesic sphere of CP_2. Very probably, this surface is not a minimal surface although the volume is finite. This is suggested by the fact that the volume element increases in comparison to hyperbolic volume element giving rise to minimal volume increases as the parameter a increases.

9.4 About Congruence Groups

Stephen Crowley made a very interesting observation about Gaussian Mersennes in the comment section of the posting *Pion of $M_{G,79}$ hadron physics at LHC?* (see `http://tinyurl.com/y8hx3fft`). I glue the comment below.

Matti, why Low Gaussian primes? Your list of primes is a subset of the factors of the dimension of the friendly giant group.

The monster group (see `http://tinyurl.com/ydxpekmp`) was investigated in the 1970s by mathematicians Jean-Pierre Serre, Andrew Ogg and John G. Thompson; they studied the quotient of the hyperbolic plane by subgroups of $SL2(R)$, particularly, the normalizer $\Gamma_0(p)_+$ of $\Gamma_0(p)$ in $SL(2,R)$. They found that the Riemann surface resulting from taking the quotient of the hyperbolic plane by $\Gamma_0(p)_+$ has genus zero if and only if p is 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 41, 47, 59 or 71. When Ogg heard about the monster group later on, and noticed that these were precisely the prime factors of the size of Monster, he published a paper offering a bottle of Jack Daniel's whiskey to anyone who could explain this fact (Ogg (1974)).

I must first try to clarify to myself some definitions so that I have some idea about what I am talking about.

1. Congruence group $\Gamma_0(p)$ is the kernel of the modulo homomorphism mapping $SL(2,Z)$ to $SL(2,Z/pZ)$ and thus consists of $SL(2,Z)$ matrices which are are unit matrices modulo p. More general congruence subgroups $SL(2,Z/nZ)$ are subgroups of $SL(2,Z/pZ)$ for primes p dividing n. Congruence group can be regarded as subgroup of p-adic variant of $SL(2,Z)$ with elements restricted to be finite as real integers. One can give up the finiteness in real sense by introducing p-adic topology so that one has $SL(2,Z_p)$. The points of hyperbolic plane at the orbits of the normalizer of $\Gamma_0(p)_+$ in $SL(2,C)$ are identified.

2. Normalizer $\Gamma_0(p)_+$ is the subgroup of $SL(2,R)$ commuting with $\Gamma_0(p)$ but not with its individual elements. The quotient of hyperbolic space with the normalizer is sphere for primes k associated with Gaussian Mersennes up to $k = 47$. The normalizer in $SL(2,Z_p)$ would also make sense and an interesting question is whether the result can be translated to p-adic context. Also the possible generalization to $SL(2,C)$ is interesting.

First some comments inspired by the observation about Gaussian Mersennes by Stephen.

1. Gaussian primes are really big but the primes defining them are logarithmically smaller. $k = 379$ defines scale slightly large than that defined by the age of the Universe. Larger ones exist but are not terribly interesting for human physicists for a long time.

   Some primes k define Gaussian Mersenne as $M_{G,k} = (1+i)^k - 1$ and the associated real prime defined by its norm is rather large - rather near to 2^k and for $k = 79$ this is already quite big. $k = 113$ characterises muon and nuclear physics, $k = 151, 157, 163, 167$ define a number theoretical miracle in the range cell membrane thickness- size of cell nucleus. Besides this there are astro-physically and cosmoplogically important Gaussian Mersennes (see the earlier posting (see `http://tinyurl.com/yan2xh3x`)).

2. The Gaussian Mersennes below M_{89} correspond to $k = 2, 3, 5, 7, 11, 19, 29, 47, 73$. Apart from $k = 73$ this list is indeed contained by the list of the lowest monster primes $k = 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 41, 47, 59, 71$. The order d of Monster is product of powers of these primes: $d = 2^{46} \times 3^{20} \times 5^9 \times 7^6 \times 11^2 \times 13^3 \times 17 \times 19 \times 23 \times 29 \times 31 \times 41 \times 47 \times 59 \times 71$ (see `http://tinyurl.com/onl32na`).

   Amusingly, Monster contains subgroup with order, which is product of exactly those primes k associated with Gaussian Mersennes, which are definitely outside the reach of LHC! Should one call this subgroup Particle Physics Monster? Number theory and particle physics would meet each other! Or actually they would not!

   Speaking seriously, could this mean that the high energy physics above $M_{G,79}$ energy is somehow different from that below in TGD Universe? Is $k = 47$ somehow special: it correspond to energy scale 17.6×10^3 TeV=17.6 PeV (P for Peta). Pessimistic would argue that this scale is the Monster energy scale never reached by human particle physicists.

The continuations of congruence groups and their normalizers to the p-adic variants $SL(2,Z_p)$ of $SL(2,Z+iZ)$ ($SL(2,C)$) are very interesting in TGD framework and are expected to appear in the adelization. Now hyperbolic plane is replaced with 3-D hyperbolic space H^3 (mass shell for particle physicist and cosmic time constant section for cosmologist).

1. One can construct hyperbolic manifolds as spaces of the orbits of discrete subgroups in 3-D hyperbolic space H^3 if the discrete subgroup defines tessellation/lattice of H^3. These lattices are of special interest as the discretizations of the H^3 parametrizing the position for the second tip of causal diamond (CD) in zero energy ontology (ZEO), when the second tip is fixed. By number theoretic arguments this moduli space should be indeed discrete.

2. In TGD inspired cosmology the positions of dark astrophysical objects could tend to be localized in hyperbolic lattice and visible matter could condense around dark matter. There are infinite number of different lattices assignable to the discrete subgroups of $SL(2,C)$. Congruence subgroups and/or their normalizers might define p-adically natural tessellations. In ZEO this kind of lattices could be also associated with the light-like boundaries of CDs obtained as the limit of hyperbolic space defined by cosmic time constant hyperboloid as cosmic time approaches zero (moment of big bang). In biology there is evidence for coordinate grid like structures and I have proposed that they might consist of magnetic flux tubes carrying dark matter.

   Only a finite portion of the light-cone boundary would be included and modulo p arithmetics refined by using congruence subgroups $\Gamma_0(p)$ and their normalizers with the size scale of CD identified as secondary p-adic time scale could allow to describe this limitation mathematically. $\Gamma(n)$ would correspond to a situation in which the CD has size scale given by n instead of prime: in this case, one would have multi-p p-padicity.

3. In TGD framework one introduces entire hierarchy of algebraic extensions of rationals. Preferred p-adic primes correspond to so called ramified primes of the extension. p-Adic continuations identifiable as imaginations would be due to the existence of p-adic pseudo-constants. The continuation could fail for most configurations of partonic 2-surfaces and string world sheets in the real sector: the interpretation would be that some space-time surfaces can be imagined but not realized [K24]. For certain extensions the number of realizable imaginations could be exceptionally large. These extensions would be winners in the number theoretic fight for survivalandcorresponding ramified primes would be preferred p-adic primes.

   Also p-adic length scale hypothesis can be understood and generalized if one accepts Negentropy Maximization Principle (NMP) and the notion of negentropic entanglement. Given extension of rationals induces an extension of p-adic numbers for each p, and one obtains extension of of ordinary adeles. Algebraic extension of rationals leads also an extension of $SL(2,Z)$. Z can be replaced with any extension of rationals and has p-adic counterparts associated with p-adic integers of extensions of p-adic numbers. The notion of primeness generalizes and the congruence subgroups $\Gamma_0(p)$ generalize by replacing p with prime of extension.

Above I have talked only about algebraic extensions of rationals. p-Adic numbers have however also finite-dimensional algebraic extensions, which are not induced by those of rational numbers.

1. The basic observation is that e^p exists as power series p-adically as p-adic integer of norm 1 - e^p cannot be regarded as a rational number. One can introduce also roots of e^p and define in these manner algebraic extensions of p-adic numbers. For rational numbers the extension would be algebraically infinite-dimensional.

   In real number based Lie group theory e is in special role more or less by convention. In p-adic context the situation changes. p-adic variant of a given Lie group is obtained by exponentiation of elements of Lie algebra which are proportional to p (one obtains hierarchy of sub-Lie groups in powers of p) so that the Taylor series converges p-adically.

   These subgroups and algebraic groups generate more interesting p-adic variants of Lie groups: they would decompose into unions labelled by the elements of algebraic groups, which are multiplied by the p-adic variant of Lie group. The roots of e are mathematically extremely natural serving as hyperbolic counterparts for the roots of unity assignable to ordinary angles necessary if one wants to talk about the notion of angle and perform Fourier analysis in p-adic context: actually one can speak only about trigonometric functions of angles p-adically but not about angles. Same is true in hyperbolic sector.

2. The extension of p-adics containg roots of e could even have application to cosmology! If the dark astrophysical objects tend to form hyperbolic lattices and visible matter tends to condensed around lattice points, cosmic redshifts tend to have quantized values. This tendency is observed. Also roots of e^p could appear. The recently observed evidence for the oscillation of the cosmic scale parameter could be understood if one assumes this kind of dark matter lattice, which can oscillate. Roots of e^2 appear in the model! (see the posting *Does the rate of cosmic expansion oscillate?* at `http://tinyurl.com/ybudjrul`). Analogous explanation in terms of dark matter oscillations applies to the recently observed anomalous periodic variations of Newton's constant measured at the surface of Earth and of the length of day. (see *Variation of Newton's constant and of length of day at* `http://tinyurl.com/ybywy73w`*)) [L8].*

3. *Things can get even more complex! e^π converges π-adically for any generalized p-adic number field defined by a prime π of an algebraic extension and one can introduce genuinely p-adic algebraic extensions by introducing roots $e^{\pi/n}$! This raises interesting questions. How many real transcendentals can be represented in this manner? How well the hierarchy of adeles associated with extensions of rationals allowing also genuinely p-adic finite-dimensionals extensions of p-adics is able to approximate real number system? For instance, can one represent π in this manner?*

9.5 Quasicrystals

One can also ask whether hyperbolic quasicrystals are possible. In the following some basic facts about quasicrystals are summarized and some questions relating to the dynamics of quasicrystals are considered before brief comments on hyperbolic quasicrystals.

9.5.1 Basic facts about quasicrystals

Quasicrystals are lattices, which do not have translational symmetries. Quasicrystals can be finite or infinite and only in special cases local matching rules give rise to infinite quasicrystal instead of finite local empire (to be defined later). The so called empire problem for Penrose tilings (see `http://tinyurl.com/yc75bvd8`) has been solved by Laura Effinger-Dean [A20].

1. Especially interesting example about quasiperiodic 2-D lattices are Penrose tilings (see `http://tinyurl.com/y8cddhz6`) [A9] for which basic objects have 5-fold local rotation symmetry: this is not allowed in ordinary crystallography. They are also self-similar. Their number is uncountably infinite. There is a theorem [A9] stating that Penrose tilings are obtained as projections of 5-dimensional lattices to 2-D plane imbedded in 5-D Euclidian space. If the parameters characterizing the plane have irrational values one obtains quasicrystal. This theorem generalizes to Euclidian spaces E^n imbbedded to higher-dimensional Euclidian spaces E^{n+k} carrying lattice structure.

2. In the case of Penrose tiling the plane is characterized by its normal space characterizing the orientation of the plane: for rational values of the "slope" of the plane one obtains periodic lattices with finite number of points projected to same point at E^2. For irrationals slopes just one point is projected to a given point of E^2. One can regard the space of the plane embeddings containing also Penrose tilings as a coset space $SO(5)/SO(2) \times SO(3)$ having dimension $D = 10 - 1 - 3 = 6$. The space for Penrose tilings (with crystals excluded) is rather delicate mathematical notion and represents basic example of a non-commutative geometry [A21].

3. An important concept related to Penrose tilings is the notion of already mentioned [A20]. One starts from a given "seed" for a quasicrystal, and builds a larger quasicrystal using local matching rules forbidding gaps. Local empire is the largest quasicrystal obtained in this manner and is a connected structure. Empire in turn is the largest set of tiles shared by all tilings containing the "seed" and is in general non-connected and can be even infinite. For ordinary crystals single unit cell fixes the lattice completely as its empire.

9.5.2 About dynamics of quasicrystals

Consider next possible dynamics of quasicrystals.

1. The fact that the local matching rules are not enough to construct infinite quasicrystal uniquely and that there is no guarantee that a given seed leads to infinite quasicrystal led Penrose to ask whether the formation of quasicrystal involves macroscopic quantum phase transition in which quasicrystal is created in single quantum leap rather than being a result of growth process. Experimentalist can of course argue that real quasicrystals are always infinite and this is just because the growth process stops because local matching rules fail at some step.

2. The conditions that quasicrystal property is preserved in the dynamics of quasicrystal is extremely strong. One manner to satisfy it would be the reduction of the dynamics to dynamics in the space of quasicrystals and crystals. The rigid body dynamics associated with the rotation of E^n in E^{n+k} containing the mother crystal would induce the variation of the projection of the crystal to E^n containing also quasicrystal configurations. In the case of embeddings $E^2 \subset E^5$ containing also Penrose tilings, the analog of rigid body motion would take place in $SO(5)/SO(3) \times SO(2)$. This dynamics can be solved both classically and quantum mechanically. The special feature of the dynamics would be correlation between short and long scale aspects of the dynamics since both local consistency rules and global consistency rules are automatically satisfied.

3. Quasicrystal excitations are known as phasons (see `http://tinyurl.com/ycb86kzc`) [D4]. The intriguing observation is that they can be described using hydrodynamics (long length scale description) and microscopically as re-arrangements of nearby atoms. There is a strong correlation between short and long length scales. If quasicrystal property is preserved by the dynamics, this is expected. The reduction to rigid body dynamics with only 6 degrees of freedom might of course be quite too restrictive an assumption and it is quite possible that the excitations have nothing to do with quasicrystallinity. Macroscopic quantum transitions can be also considered. The most mundane explanation would be in terms of thermodynamics: in ZEO square root of thermodynamics could unify quantal and thermodynamical explanations.

9.5.3 What about hyperbolic quasicrystals?

Hyperbolic 2-D quasicrystals are of special interest in TGD since they can be assigned to the spaces H^2 imbedded to H^3. Could one generalize the construction of Penrose tilings to a construction recipe for hyperbolic quasicrystals? For the hyperbolic counterparts of Penrose tilings one could imagine isometric embedding of $H^2 \subset H^n$, $n > 2$. H^3 is the physically preferred option in TGD. Embedding would represent 2-D hyperboloid $H^2 = SO(1,2)/SO(2)$ of M^3 as constant sectional curvature sub-manifold of n-dimensional hyperboloid in $H^n = SO(1,n)/SO(n)$. There is a continuum of this kind of embeddings. In the compact case one has embeddings of S^2 to S^3 and the space of embeddings is $SO(3)/SO(1) \times SO(2) = S^1$. Same holds true in the hyperbolic case. For $H^n \subset H^{n+k}$ one has $SO(n+k)/SO(n) \times SO(k)$. One can consider also 3-D hyperbolic quasicrystals and the embedding $H^3 \to H^n$, $n > 3$ might gives this kind of quasicrystals. This embedding would not however have a concrete geometric interpretation in TGD framework.

Could hyperbolic 2-planes or finite pieces of them allow a physical interpretation as 2-D physical systems in cosmological scales? Certainly the existence of quasicrystals and even more that of crystals in cosmological scales requires quantum coherence in cosmological scales, and dark matter and dark energy as phases with large and even gigantic value of Planck constant [K13] [L3] could give rise this kind of structures.

9.6 Could Quasi-Lattices And Quasi-Crystals Emerge From TheNotion Of P-Adic Manifold?

This section is inspired by the considerations of the new chapter "What p-adic icosahedron could mean? And what about p-adic manifold?" [K41]. The original purpose was to understand what the notion of p-adic icosahedron could mean but soon it turned out that the key challenge is to understand what p-adic manifold means. Also in TGD framework this is one of the basic challenges posed by the condition of number theoretical universality and the idea about algebraic continuation of physics between different number fields.

The basic problem is that p-adic topology is totally disconnected meaning that p-adic balls are either disjoint or nested so that the usual construction of manifold structure fails. The basic criticism against the notion of p-adic icosahedron, and more generally, the notion of p-adic manifold, is the technical complexity of the existing constructions by mathematicians.

TGD however suggests much simpler construction. The construction relies on a simple modification of the notion of manifold inspired by the interpretation of p-adic preferred extremals defining counterparts of real preferred extremals as cognitive representations of the latter. This requires a mapping from p-adic preferred extremals to real ones and vice versa. In manifold theory chart maps are the analogs of these maps and the only difference is that they are between different number fields (see the appendix of the book).

What I have christened as canonical identification $I_{k,l}^Q$ mapping rationals $p^{rk}m/n$ with $|m|_p > p^{-k}$, $|n|_p > p^{-k}$, as $I_{k,l}^Q(p^{rk}(m/n)) = p^{-rk}I_{k,l}(m)/I_{k,l}(n)$, where $I_{k,l}(m = \sum m_n p^{nk}) = \sum_{n<l} m_n p^{-nk}$ defines canonical identification for p-adic numbers m, n satisfying the above conditions in their pinary expansion with two cutoffs k and l. $I_{k,l}^Q$ is ill defined for irrational p-adic numbers since for them the representation as rational is not unique. A generalization to algebraic extensions is straightforward.

$I_{k,l}^Q$ is a compromise between the direct identification along common rationals favored by algebra and symmetries but being totally discontinuous without the cutoff $n < l$. This cutoff breaks symmetries slightly but guarantees continuity in finite measurement resolution defined by the pinary cutoff l. Symmetry breaking can be made arbitrarily small and has interpretation in terms of finite measurement resolution. Due to the pinary cutoff the chart map applied to various p-adic coordinates takes discrete set of rationals to discrete set of rationals and preferred extremal property can be used to make a completion to a real space-time surface. Uniqueness is achieved only in finite measurement resolution and is indeed just what is needed. Also general coordinate invariance is broken in finite measurement resolution. In TGD framework it is however possible to find preferred coordinates in order to minimize this symmetry breaking.

9.6.1 TGD based view about p-adic manifolds

The construction of p-adic manifold topology somehow overcoming the difficulty posed by the fact that p-adic balls are either disjoint or nested is necessary. It should also allow a close relationship between p-adic and real preferred extremals. It will be found that TGD leads naturally to a proposal of p-adic manifold topology [K41] based on canonical identification used to map the predictions of p-adic mass calculations to real numbers. This map would define coordinate charts for p-adic space-time surfaces - not as p-adic chart leafs as in the standard approach - but as real chart leafs. The real topology induced from real map leafs to the p-adic realm would be path-connected as required (see **Fig.** `http://tgdtheory.fi/appfigures/padmanifold.jpg` or **Fig. ??** in the appendix of this book).

In TGD framework one must also require finite measurement resolution meaning that the canonical identification is characterized by pinary cutoff takes a discrete subset of rational points of p-adic preferred extremal to its real counterpart: for a subset of this subset rationals are mapped to themselves. One can complete this point set to a real preferred extremal in finite measurement resolution. This construction allows also to define p-adic integrals and differential forms in terms of their real counterparts by algebraic continuation. Therefore geometric notions like distance and volume make sense and there is a very close correspondence between real space-time geometries and their p-adic counterpart in the situations when they exist.

9.6.2 Can one consider a p-adic generalization of Penrose tiling and quasicrystals?

The mathematically rigorous generalization of Penrose Tilings and quasicrystals to p-adic context might be possible but is bound to be rather technical. The p-adic icosahedron as it is defined in the article does not seem very promising notion. The point is that it is defined in terms of fixed point set for subgroups of icosahedral group acting on Riemann sphere: the action in Euclidian 3-space is now more natural and certainly makes sense and actually simplifies the situation since Q_p^3 sd analog of E^3 is simplest possible 3-D p-adic manifold. It does not however allow Bruhat-Tits tree since the points of Q_p^n are not in 1-1 correspondence with the lattices of Q_p^n. The possibility to construct Bruhat-Tits tree is a special feature of projective spaces.

TGD based view about p-adic E^3 and S^2 as its sub-manifold allows to define also the counterpart of Penrose tiling and QCs in an elegant manner with a close relationship between real and p-adic variants of QC.

1. If one considers lattices in n-dimensional p-adic space Q_p^n replacing E^n, a more natural definition would be in terms of this space than in terms of sphere. For the counterpart of E^3 one can define the action of the subgroup A_5 of rotation group $SO(3)$ by introducing an algebraic extension of the p-adic numbers containing $cos(2\pi/5)$, $sin(2\pi/5)$ and $cos(2\pi/3)$, $sin(2\pi/3)$ and their products. What is interesting is that algebraic extension is forced automatically in p-adic context! In cut and project (see `http://tinyurl.com/ybdbvjoa`) method [A19] the QC structure requires also this since the imbedded space has an algebraic dimension over integers equal to the dimension of the embedding space over reals.

   Could it be that p-adic variants of QCs might provide number theoretic insights about QCs? Subspace would define algebraic extension of p-adic numbers and this extension would be such that it allows the representation of the isometry group of the Platonic solid possibly assignable to the QC.

2. One can also now define the icosahedron or any Platonic solid in terms of fixed points also now. Only discrete subgroups of the rotation group can be represented p-adically since algebraic extension is required. This brings in mind the notion of finite measurement resolution

leading to a discretization of p-adically representable rotations and more general symmetries. For instance, without algebraic extension only rotations for which the rotation matrices are rational numbers are representable. It seems that finite subgroups of this kind are generated by rotations with rotation angle $\pi/2$ around various coordinate axes. Pythagorean triangles correspond to rationals values of cosine and sine and rotations for which rotation angle corresponds to Pythagorean angle define rational rotation matrices: these groups are discrete but contain infinite number of elements.

Altogether this suggests a hierarchy of p-adic extensions leading to higher algebraic dimensions and larger discrete symmetries. This conforms with the general number theoretic vision about TGD.

3. Lattices in Q_p^n with integer coefficients make also sense and are characterized by n linearly independent (over p-adic integers) basic vectors $(a_1, ..., a_n)$. Most points of lattice would correspond to values of p-adic integers n_i in $\sum_i n_i a_i$ infinite as real numbers.

   Consider first a non-realistic option in which p-adic integers are mapped to p-adic integers as such. Note also that most of p-adic lattice points would map to real infinity. This kind of correspondence makes sense also for rationals but would give a totally discontinuous correspondence between reals and p-adics.

   p-Adic manifold topology defined in terms of the canonical identification I_{kl} allows to interpret the p-adic lattice as a cognitive representation of the real one. The presence of pinary cutoffs k and l having interpretation in terms of finite cognitive resolution has two implications. Integers $n_i < p^k$ are mapped to themselves so that this portion of lattice is mapped to itself faitfully. The integers $k \leq n < l$ are not mapped to integers and the length of the image is bounded below. The real image of the p-adic lattice under I_{kl} is necessary compressed to a finite volume of E^3. This kind of compression and cutoff is natural for cognitive representations for which numerics with finite cutoff provides one particular analogy.

4. Could the notion of p-adic QC and Penrose tiling make sense if one considers p-adic counterparts of Euclidian space and a n-D cubic lattice with integer valued coefficients and spanned by unit vectors? Could the cut and project method [A19] generalize?

   This is not clear since projection would lead from a lattice in Q_p^n to a QC in lower-dimensional space which is associated with algebraic extension of Q_p but having algebraic dimension equal to n. If this space is K^m, K an algebraic extension of Q_p, one has $n = dim(K) \times m$. For prime values of n this would mean that $m = 1$ and one has n-D algebraic extension.

   Projection should be generalized to a map mapping points of n-D space to m-dimensional subspace K^m associated with algebraic extension of Q_p. Maybe it is better to formally extend Q_p^n to K^n and restrict the lattice to integer lattice in $Q_p^n \subset K^n$. In this manner the projection becomes well-defined as map from $Q_p^n \subset K^n$ to a subspace K^m of K^n. The basic condition could be that the points of the subspace K^m in K^n with algebraic dimension $n \times dim(K)$ define and m-dimensional subspace over K and n-dimensional subspace of Z_p.

   The "irrational angles" associated with the lower-dimensional subspace defining quasilattice defining algebraic extension of Q_p should be such that it allows the representation of the isometry group of the p-adic Platonic solid possibly assignable to the QC in question.

9.6.3 Cut and project construction of quasicrystals from TGD point of view

Cut and project (see `http://tinyurl.com/ybdbvjoa`) [A19] method is used to construct quasicrystals (QCs) in sub-spaces of a higher-dimensional linear space containing an ordinary space filling lattice, say cubic lattice. For instance, 2-D Penrose tiling is obtained as a projection of part of 5-D cubic lattice - known as Voronyi cell - around 2-D sub-space imbedded in five-dimensional space. The orientation of the 2-D sub-space must be chosen properly to get Penrose tiling. The nice feature of the construction is that it gives the entire 2-D QC. Using local matching rules the construction typically stops.

1. *Sub-manifold gravity and generalization of cut and project method*

The representation of space-time surfaces as sub-manifolds of 8-D $H = M^4 \times CP_2$ can be seen as a generalization of cut and project method.

1. The space-time surface is not anymore a linear 4-D sub-space as it would be in cut and project method but becomes curved and can have arbitrary topology. The embedding space ceases to be linear $M^8 = M^4 \times E^4$ since E^4 is compactified to CP_2. Space-time surface is not a lattice but continuum.

2. The induction procedure geometrizing metric and gauge fields is nothing but projection for H metric and spinor connection at the continuum limit. Killing vectors for CP_2 isometries can be identified as classical gluon fields. The projections of the gamma matrices of H define induced gamma matrices at space-time surface. The spinors of H contain additional components allowing interpretation in terms of electroweak spin and hyper-charge.

2. Finite measurement resolution and construction of p-adic counterparts of preferred extremals forces "cut and project" via discretization

In finite measurement resolution realized as discretization by finite pinary cutoff one can expect to obtain the analog of cut and project since 8-D embedding space is replaced with a lattice structure.

1. The p-adic/real manifold structure for space-time is induced from that for H so that the construction of p-adic manifold reduces to that for H.

2. The definition of the manifold structure for H in number theoretically universal manner requires for H discretization in terms of rational points in some finite region of M^4. Pinary cutoffs- two of them - imply that the manifold structures are parametrized by these cutoffs charactering measurement resolution. Second cutoff means that the lattice structure is piece of an infinite lattice. First cutoff means that only part of this piece is a direct imagine of real/p-adic lattice on p-adic/real side obtained by identifying common rationals (now integers) of real and p-adic number fields. The mapping of this kind lattice from real/p-adic side to p-adic/real side defines the discrete coordinate chart and the completion of this discrete structure to a preferred extremal gives a smooth space-time surface also in p-adic side if it is known on real side (and vice versa).

3. Cubic lattice structures with integer points are of course the simplest ones for the purposes of discretization and the most natural choice for M^4. For CP_2 the lattice is completely analogous to the finite lattices at sphere defined by orbits of discrete subgroups of rotation group and the analogs of Platonic solids emerge. Probably some mathematician has listed the Platonic solids in CP_2.

4. The important point is that this lattice like structure is defined at the level of the 8-D embedding space rather than in space-time and the lattice structure at space-time level contains those points of the 8-D lattice like structure, which belong to the space-time surface. Finite measurement resolution suggests that all points of lattice, whose distance from space-time surface is below the measurement resolution for distance are projected to the space-time surface. Since space-time surface is curved, the lattice like structure at space-time level obtained by projection is more general than QC.

The lattice like structure results as a manifestation of finite measurement resolution both at real and p-adic sides and can be formally interpreted in terms of a generalization of cut and project but for a curved space-time surface rather than 4-D linear space, and for H rather than 8-D Minkowski space. It is of course far from clear whether one can obtain anything looking like say 3-D or 4-D version of Penrose tiling.

1. The size scale of CP_2 is so small (10^4 Planck lengths) that space-time surfaces with 4-D M^4 projection look like M^4 in an excellent first approximation and using M^4 coordinates the projected lattice looks like cubic lattice in M^4 except that the distances between points are not quite the M^4 distances but scaled by an amount determined by the difference between

induced metric and M^4 metric. The effect is however very small if one believes on the general relativistic intuition.

In TGD framework one however can have so called warped embeddings of M^4 for which the component of the induced metric in some direction is scaled but curvature tensor and thus gravitational field vanishes. In time direction this scaling would imply anomalous time dilation in absence of gravitational fields. This would however cause only a the compression or expansion of M^4 lattice in some direction.

2. For Euclidian regions of space-time surface having interpretation as lines of generalized Feynman diagrams M^4 projection is 3-dimensional and at elementary particle level the scale associated with M^4 degrees of freedom is roughly the same as CP_2 scale. If CP_2 coordinates are used (very natural) one obtains deformation of a finite lattice-like structure in CP_2 analogous to a deformation of Platonic solid regarded as point set at sphere. Whether this lattice like structure could be seen as a subset of infinite lattice is not clear.

3. One can consider also string like objects $X^2 \times Y^2 \subset M^4 \times CP_2$ with 2-D M^4 projection and their deformations. In this case the projection of M^4 lattice to X^2 - having subset of two M^4 coordinates as coordinates - can differ considerably from a regular lattice since X^2 can be locally tilted with respect to M^4 lattice. This cannot however give rise to Penrose tiling requiring 5-D flat embedding space. This argument applies also to 2-D string world sheets carrying spinor modes. In the idealized situation that string world sheet is plane in M^4 one might obtain an analog of Penrose tiling but with 4-D embedding space.

The above quasi lattice like structures (QLs) are defined by a gravitational deformation of the cubic lattice of M^4. Is there any hope about the 4-D QLs in M^4 so that gravitation would give rise to the analogs of phason waves deforming them? Could cut and project method be generalized to give QL in M^4 as projection of 8-D cubic lattice in M^8?

3. $M^8 - H$ duality

Before considering an explicit proposal I try to describe what I call $M^8 - H$ duality ($H = M^4 \times CP_2$).

1. What I have christened $M^8 - H$ duality is a conjecture stating that TGD can be equivalently defined in M^8 or $M^4 \times CP_2$. This is the number theoretic counterpart of spontaneous compactification of string models but has nothing to do with dynamics: only two equivalent representations of dynamics would be in question.

2. Space-time surfaces (preferred extremals) in M^8 are postulated to be quaternionic sub-manifolds of M^8 possessing a fixed $M^2 \subset M^4 \subset M^8$ as sub-space of tangent space. “Quaternionic” means that the tangent space of M^4 is quaternionic and thus associative. Associativity conditions would thus determine classical dynamics. More generally, these subspaces $M^2 \subset M^8$ can form integrable distribution and they define tangent spaces of a 2-D sub-manifold of M^4. If this duality really holds true, space-time surfaces would define a lattice like structure projected from a cubic M^8 lattice. This of course does not guarantee anything: $M^8 - H$ duality itself suggests that these lattice like structures differ from regular M^4 crystals only by small gravitational effects.

3. The crucial point is that quaternionic sub-spaces are parametrized by CP_2. Quaternionic 4-surfaces of $M^8 = M^4 \times CP_2$ containing the fixed $M^2 \subset M^8$ can be mapped to those of $M^4 \times CP_2$ by defining M^4 coordinates as projections to preferred $M^4 \subset M^8$ and CP_2 coordinates as those specifying the tangent space of 4-surface at given point.

4. A second crucial point is that the preferred subspace $M^4 \subset M^8$ can be chosen in very many ways. This embedding is a complete analog of the embedding of lower-D subspace to higher-D one in cut and project method. M^4 can be identified as any 4-D subspace imbedded in M^4 and the group $SO(1,7)$ of 8-D Lorentz transformations defines different embeddings of M^4 to M^8. The moduli space of different embeddings of M^4 is the Grassmannian $SO(1,7)/SO(1,3) \times SO(4)$ and has dimension $D = 28 - 6 - 6 = 16$.

When one fixes two coordinate axes as the real and one imaginary direction (physical interpretation is as an identification of rest system and spin quantization axes), one obtains $SO(1,7)/SO(2) \times SO(4)$ with higher dimension $D = 28 - 1 - 6 = 21$. When one requires also quaternionic structure one obtains the space $SO(1,7)/SU(1) \times SU(2)$ with dimension $D = 28 - 4 = 24$. Amusingly, this happens to be the number of physical degrees of freedom in bosonic string model.

5. How to obtain quasilattices and quasi-crystals in M^4?

Can one obtain quasi-lattice like structures (QLs) at space-time level in this framework? Consider first the space-time QLs possibly associated with the standard cubic lattice L^4_{st} of M^4 resulting as projections of the cubic lattice structure L^8_{st} of M^8.

1. Suppose that one fixes a cubic crystal lattice in M^8, call it L^8_{st}. Standard M^4 cubic lattice L^4_{st} is obtained as a projection to some M^4 sub-space of M^8 by simply putting 4 Euclidian coordinates for lattice points o constant. These sub-spaces are analogous to 2-D coordinate planes of E^3 in fixed Cartesian coordinates. There are $7!/3!4! = 35$ choices of this kind.

   One can consider also E_8 lattice (see `http://tinyurl.com/y9x7vevr`) is an interesting identification for the lattice of M^8 since E_8 is self-dual and defines the root lattice of the exceptional group E_8. E_8 is union of Z^8 and $(Z + 1/2)^8$ with the condition that the sum of all coordinates is an even integer. Therefore all lattice coordinates are either integers or half-integers. E_8 is a sub-lattice of 8-D cubic lattice with 8 generating vectors $e_i/2$, with e_i unit vector. Integral octonions are obtained from E_8 by scaling with factor 2. For this option one can imbed L^4_{st} as a sub-lattice to Z^8 or $(Z + 1/2)^8$.

2. Although $SO(1,3)$ leaves the imbedded 4-plane M^4 invariant, it transforms the 4-D crystal lattice non-trivially so that all 4-D Lorentz transforms are obtained and define different discretizations of M^4. These are however cubic lattices in the Lorentz transformed M^4 coordinates so that this brings nothing new. The QLs at space-time surface should be obtained as gravitational deformations of cubic lattice in M^4.

3. L^4_{st} indeed defines 4-D lattice at space-time surface apart from small gravitational effects in Minkowskian space-time regions. Elementary particles are identified in TGD a Euclidian space-time regions - deformed CP_2 type vacuum extremals. Also black-hole interiors are replaced with Euclidian regions: black-hole is like a line of a generalized Feynman diagram, elementary particle in some sense in the size scale of the black-hole. More generally, all physical objects, even in everyday scales, could possess a space-time sheet with Euclidian metric signature characterizing their size (AdS^5/CFT correspondence could inspire this idea). At these Euclidian space-time sheets gravitational fields are strong since even the signature of the induced metric is changed at their light-like boundary. Could it be that in this kind of situation lattice like structures, even QCs, could be formed purely gravitationally? Probably not: an interpretation as lattice vibrations for these deformations would be more natural.

It seems that QLs are needed *already at the level of M^4*. $M^8 - H$ duality indeed provides a natural manner to obtain them.

1. The point is that the projections of L^8_{str} to sub-spaces M^4 defined as the $SO(1,7)$ Lorentz transforms of L^4_{st} define generalized QLs parametrized by 16-D moduli space $SO(1,7)/SO(1,3) \times SO(4)$. These QLs include also QCs. Presumably QC is a QL possessing a non-trivial point group just like Penrose tiling has the isometry group of dodecagon as point group and 3-D analog of Penrose tiling has the isometries of icosahedron as point group.

   This would allow to conclude that the discretization at the level of M^8 required by the definition of p-adic variants of preferred extremals as cognitive representations of their real counterparts would make possible 4-D QCs. M^8 formulation of TGD would explain naturally the QL lattices as discretizations forced by finite measurement resolution and cognitive resolution.

   A strong number theoretical constraint on these discretizations come from the condition that the 4-D lattice like structure corresponds to an algebraic extension of rationals. Even more, if this algebraic extension is 8-D (perhaps un-necessarily strong condition), there are extremely strong constraints on the 22-parameters of the embedding. Note that in p-adic context the algebraic extension dictates the maximal isometry group identified as subgroup of $SO(1,7)$ assignable to the embedding as the discussion of p-adic icosahedron demonstrates.

2. What about the physical interpretation of these QLs/QCs? As such QLs define only natural discretizations rather than physical lattices. It is of course quite possible to have also physical QLs/QCs such that the points - rather time like edge paths - of the discretization contain real particles. What about a "particle" localized to a point of 4-D lattice? In positive energy ontology there is no obvious answer to the question. In zero energy ontology the lattice point could correspond to a small causal diamond containing a zero energy state. In QFT context one would speak of quantum fluctuation. In p-adic context it would correspond to "though bubble" lasting for a finite time.

3. It is also possible to identify physical particles as edge paths of the 4-D QC, and one can consider time= constant snapshots as candidates for 3-D QCs. It is quite conceivable that the non-trivial point group of QCs favors them as physical QLs.

5. Expanding hyperbolic tessellations and quasi tessellations obtained by embedding $H^3 \subset M^4$ to $H^7 \subset M^8$

M^8-$M^4 \times CP_2$ duality and the discretization required by the notion of p-adic manifold relates in an interesting manner to expanding hyperbolic tessellations and quasi tessellations in $H^7 \subset M^8$, and possible expanding quasi-tessellations in obtained by embedding $H^3 \subset M^4$ to $H^7 \subset M^8$

1. Euclidian lattices E_8, E_7, E_6

   I have already considered E_8 lattice in M^8. The background space has however Minkowskian rather than Euclidian metric natural for the carrier space of the E_8 lattice. If one assigns some discrete subgroup of isometries to it, it is naturally subgroup of $SO(8)$ rather than $SO(1,7)$. Both these groups have $SO(7)$ as a subgroup meaning that preferred time direction is chosen as that associated with the real unit and considers a lattice formed from imaginary octonions.

   E_8 lattice scaled up by a factor 2 to integer lattice allows octonionic integer multiplication besides sums of points so that the automorphism group of octions: discreted subgroups of $G_2 \subset SO(7)$ would be the natural candidates for point groups crystals or lattice like structures.

   If one assumes also fixed spatial direction identified as a preferred imaginary unit, G_2 reduces to $SU(3) \subset SO(6) = SU(4)$ identifiable physically as color group in TGD framework. From this one ends up with the idea about $M^8 - M^4 \times CP_2$ duality. Different embeddings of $M^4 \subset M^8$ are quaternionic sub-spaces containing fixed M^2 are labelled by points of CP_2.

   All this suggests that E_7 lattice in time=constant section of even E^6 lattice is a more natural object lattice to consider. Kind of symmetry breaking scenario $E_8 \to E_7 \to E_6 \to G_2 \to SU(3)$ is suggestive. This Euclidian lattice would be completely analous to a slicing of 4-D space-time by 3-D lattices labelled by the value of time coordinate and is of course just what physical considerations suggest.

2. Hyperbolic tessellations

   Besides crystals defined by a cubic lattice or associated with E_6 or E_7, one obtains an infinite number of hyperbolic tessellations in the case of M^8. These are much more natural in Minkowskian signature and could be also cosmologically very interesting. Quite generally, one can say that hyperbolic space is ideal for space-filling packings defined by hyperbolic manifolds H^n/Γ: they are completely analogous to space-filling packings of E^3 defined by discrete subgroups of translation group producing packings of E^3 by rhombohedra. One only replaces discrete translations with discrete Lorentz transformations. This is what makes these highly interesting from the point of view of quantum gravity.

   (a) In M^{n+1} one has tessellations of n-dimensional hyperboloid H^n defined by $t^2 - x1^2 - ... - x_n^2 = a^2 > 0$, where a defines Lorentz invariant which for $n = 4$ has interpretation as cosmic time in TGD framework. Any discrete subgroup Γ of the Lorentz group $SO(1,n)$ of M^{n+1} with suitable additional conditions (finite number of generators at least) allows a tessellation of H^n by basic unit H^n/Γ. These tessellations come as 1-parameter families labelled by the cosmic time parameter a. These 3-D tessellations participate cosmic expansion. Of course, also ordinary crystals are crystals only in spatial directions. One can of course discretize the values of a or some function of a in integer multiples of basic unit and assign to each copy of H^n/Γ a "center point" to obtain discretization of M^{n+1} needed for p-adicization.

(b) For $n = 3$ one has M^4 and H^3, and this is very relevant in TGD cosmology. The parameter a defines a Lorentz invariant cosmic time for the embeddings of Robertson-Walker cosmologies to $M^4 \times CP_2$. The tessellations realized as physical lattices would have natural interpretation as expanding 3-D lattice like structures in cosmic scales. What is new is that discrete translations are replaced by discrete Lorentz boosts, which correspond to discrete velocities and observationally to discrete red shifts for distant objecst. Interestingly, it has been found that red shift is quantized along straight lines [E33]: "God's fingers" is the term used. I proposed for roughly two decades ago an explanation based on closed orbits of photons around cosmic strings [K7]. but explanation in terms of tessellations would also give rise to periodicity. A fascinating possibility is that these tessellation have defined macroscopically quantum coherent structures during the very early cosmology the size scale of H^3/Γ was very small. One can also ask whether the macroscopic quantum coherence could still be there.

Hyperbolic manifold property has purely local signatures such as angle surplus: the very fact that there are infinite number of hyperbolic tessellations is in conflict with the fact that we have Euclidian 3-geometry in every day length scales. In fact, for critical cosmologies, which allow a one-parameter family of embeddings to $M^4 \times CP_2$ (parameter characterizes the duration of the cosmology) one obtains flat 3-space in cosmological scales. Also overcritical cosmologies for which $a = constant$ section is 3-sphere are possible but only with a finite duration. Many-sheeted space-time picture also leads to the view that astrophysical objects co-move but do not co-expand so that the geometry of time=constant snapshot is Euclidian in a good approximation.

3. Does the notion of hyperbolic quasi-tessellation make sense?

Can one construct something deserving to be called quasi tessellations (QTs)? For QCs translational invariance is broken but in some sense very weakly: given lattice point has still an infinite number of translated copies. In the recent case translations are replaced by Lorentz transformations and discrete Lorentz invariance should be broken in similar weak manner.

If cut and project generalizes, QTs would be obtained using suitably chosen non-standard embedding $M^4 \subset M^8$. Depending on what one wants to assume, M^4 is now image of M^4_{st} by an element of $SO(1,7)$, $SO(7), SO(6)$ or G_2. The projection - call it P - must take place to M^4 sliced by scaled copies of H^3 from M^8_{st} sliced by scaled copies of H^7/Γ tessellation. The natural option is that P is directly from H^7 to $H^3 \subset H^7$ and is defined by a projecting along geodesic lines orthogonal to H^3. One can choose always the coordinates of M^4 and M^8 in such a way that the coordinates of points of M^4 are $(t,x,y,z,0,0,0,0)$ with $t^2 - r^2 = a_4^2$ whereas for a general point of H^7 the coordinates are $(t,x,y,z,x_4,...x_7)$ with $t^2 - r^2 - r_4^2 = a_8^2$ for $H^3 \subset H^7$. The projection is in this case simply $(t,x,y,z,x_4,...,x_7) \rightarrow (t,x,y,z,0,...,0)$. The projection is non-empty only if one has $a_4^2 - a_8^2 \geq 0$ and the 3-sphere S^3 with radius $r_4 = \sqrt{a_4^2 - a_8^2}$ is projected to single point. The images of points from different copies of H^7/Γ are identical if S^3 intersects both copies. For r_4 much larger than the size of the projection $P(H^7/\Gamma)$ of single copy overlaps certainly occurs. This brings strongly in mind the overlaps of the dodecagons of Penrose tiling and icosahedrons of 3-D icosahedral QC. The point group of tessellation would be Γ.

4. Does one obtain ordinary H^3 tessellations as limits of quasi tessellations?

Could one construct expanding 3-D hyperbolic tessellations H_3/Γ_3 from expanding 7-D hyperbolic tessellations having H^7/Γ_7 as a basic building brick? This seems indeed to be the outcome at at the limit $r_4 \to 0$. The only projected points are the points of H^3 itself in this case. The counterpart of the group $\Gamma_7 \subset SO(1,7)$ is the group obtained as the intersection $\Gamma_3 = \Gamma_7 \cap SO(1,3)$: this tells that the allowed discrete symmetries do not lead out from H^3. This seems to mean that the 3-D hyperbolic manifold is H^3/Γ_3, and one obtains a space-filling 3-tessellation in complete analogy for what one obtains by projecting cubic lattice of E^7 to E^3 imbedded in standard manner. Note that $\Gamma_3 = \Gamma_7 \cap SO(1,3)$, where $SO(1,3) \subset SO(1,7)$, depends on embedding so that one obtains an infinite family of tessellations also from different embeddings parametrized by the coset space $SO(1,7)/SO(1,3)$. Note that if Γ_3 contains only unit element $H^3 \subset H^7/\Gamma_7$ holds true and tessellation trivializes.

10 About syncronization of clocks

This section originated from a debate with some anti-Einsteinians about synchronization of clocks. At modern times physicists regard this kind of ponderings "philosophical" and something negative. The discussion however led to the question whether it is possible to synchronize clocks in Lorentz invariant manner. The answer to this question is positive quite generally in TGD - put the clocks at hyperboloid of light-cone- and leads to a vision about synchronization in terms of quantum entanglement in a tensor network defined by a tessellation of hyperboloid of M^4.

10.1 Einstein did not assume that clock synchorinization is Lorentz invariant

I participated an FB discussion with several anti-Einsteinians. As a referee I have expressed my opinion about numerous articles claiming that Einstein's special or general relativity contains a fatal error not noticed by any-one before. I have tried to tell that colleagues are extremely eager to find a mistake in the work of colleague so that logical errors can be safely excluded. If something goes wrong it is at the level of basic postulates. In vain.

Once I had a long email discussion with a professor of logic who claimed to have found logical mistake in the deduction of time dilation formula. It was easy to find that he thought in terms of Newtonian space-time and this was of course in conflict with relativistic view. The logical error was his, not Einstein's. I tried to tell this. In vain again.

At this time I was demanded to explain why the 2 page article of Stephen Crothers (see `http://tinyurl.com/yc2qqncz`). This article was a good example of own logical error projected to that of Einstein. The author assumed besides the basic formulas for Lorentz transformation also synchronization of clocks so that they show the same time everywhere (about how this is achieved see `http://tinyurl.com/jdccns4n`).

Even more: Crothers assumes that *Einstein assumed* that this synchronization is Lorentz invariant. Lorentz invariant synchronization of clocks is not however possible for the linear time coordinate of Minkowski space as also Crothers demonstrates. Einstein was wrong! Or was he? No!: Einstein of course did not assume Lorentz invariant synchronization!

The assumption that the synchronization of clock network is invariant under Lorentz transformations is of course in conflict with SR. In Lorentz boosted system the clocks are not in synchrony. This expresses just Einstein's basic idea about the relativity of simultaneity. Basic message of Einstein is misunderstood!

The basic predictions of SR - time dilation and Lorentz contraction - do not depend on the model of synchronization of clocks . Time dilation (see `http://tinyurl.com/qdnn5h9`) and Lorentz contraction (see `http://tinyurl.com/nuxr9db`) follow from the basic geometry of Minkowskian space-time extremely easily.

Draw system K and K' moving with constant velocity with respect to K. The t' and x' axis of K' have angle smaller than $\pi/2$ and are the in first quadrant.

1. Assume first that K corresponds to the rest system of particle. You see that the projection of segment $(0,t')$ of t'-axis to t-axis is shorter than the segment $(0,t)$: time dilation.

2. Take K to be the system of stationary observer. Project the segment $L = (0, x')$ to segment on x axis. It is shorter than L: Lorentz contraction.

There is therefore no need to build synchronized networks of clocks to deduce time dilation and Lorentz contraction. They follow from Minkowskian geometry.

10.2 Is it possible to have Lorentz invariant synchronization?

The above argument raises a question. Is it possible to find a system in which synchronization is possible in Lorentz invariant manner? The quantity $a^2 = t^2 - x^2$ defines proper time coordinate a along time like geodesics as Lorentz invariant time coordinate of light-one. a = constant hyper-surfaces are now hyperboloids. If you have a synchronized network of clocks, its Lorentz boost is also synchronized. General coordinate invariance of course allows this choice of time coordinate.

For Robertson-Walker cosmologies with sub-critical mass time coordinate a is Lorenz invariant so that one can have Lorentz invariant synchronization of clocks. General Coordinate Invariance allows infinitely many choices of time coordinate and the condition of Lorentz invariant synchronization fixes the time coordinate to cosmic time (or its function to be precise). To my opinion this is rather intesting fact.

What about TGD? In TGD space-time is 4-D surface in $H = M^4 \times CP_2$. $a^2 = t^2 - r^2$ defines Lorentz invariant time coordinate a in future light-cone $M^4_+ \subset M^4$ which can be used as time-coordinate also for space-time surfaces.

Robertson-Walker cosmologies can be imbedded as 4-surfaces to $H = M^4 \times CP_2$. The empty cosmology would be just the lightcone M^4_+ imbedded in H by putting CP_2 coordinates constant. If CP_2 coordinates depend onM^4_+ proper time a, one obtains more general expanding RW cosmologies. One can have also sub-critical and critical cosmologies for which Lorentz transformations are not isometries of a= constant section. Also in this case clocks are synchronized in Lorentz invariant manner. The duration of these cosmologies is finite: the mass density diverges after finite time.

10.3 What about actual realization of Lorentz invariant synchronization?

What about actual Lorentz invariant synchronization of the clocks? Could TGD say something non-trivial about this problem? I received an interesting link relating to this (see `http://tinyurl.com/gkr62bt`). The proposed theory deals with fundamental uncertainty of clock time due to quantum-gravitational effects. There are of course several uncertainties involved since quantum theory of gravity does not exist (officially) yet!

1. Operationalistic definition of time is adopted in the spirit with the empiristic tradition. Einstein was also empirist and talked about networks of synchronized clocks. Nowadays particle physicists do not talk much about them. Symmetry based thinking dominates and Special Relativity is taken as a postulate about symmetries.

2. In quantum gravity situation becomes even rather complex. If quantization attempt tries to realize quantum states as superpositions of 3-geometries one loses time totally. If GRT space-time is taken to be small deformation of Minkowski space one has path integral and classical solutions of Einstein's equation define the background.

   The difficult problem is the identification of Minkowski coordinates unless one regards GRT as QFT in Minkowski space. In astrophysical scales QFT picture one must consider solutions of Einstein's equations representing astrophysical objects. For the basic solutions of Einstein's equations the identification of Minkowski coordinates is obvious but in general case such as many-particle system this is not anymore so. This is a serious obstacle in the interpretation of the classical limit of GRT and its application to planetary systems.

What about the situation in TGD? Particle physicist inside me trusts symmetry based thinking and has been somewhat reluctant to fill space-time with clocks but I am ready to start the job if necessarily! Since I am lazy I of course hope that Nature might have done this already and the following argument suggests that this might be the case!

1. Quantum states can be regarded as superpositions of space-time surfaces inside causal diamond of embedding space $H = M^4 \times CP_2$ in quantum TGD. This raises the question how one can define universal time coordinate for them. Some kind of absolute time seems to be necessary.

2. In TGD the introduction of zero energy ontology (ZEO) and causal diamonds (CDs) as perceptive fields of conscious entities certainly brings in something new, which might help. CD is the intersection of future and past directed light-cones analogous to a big bang followed by big crunch. This is however only analogy since CD represents only perceptive field not the entire Universe.

   The imbeddability of space-time as to $CD \times CP_2 \subset H = M^4 \times CP_2$ allows the proper time coordinate $a^2 = t^2 - r^2$ near either CD bouneary as a universal time coordinate, "cosmic time". At $a=$ constant hyperboloids Lorentz invariant synchronisation is possible. The coordinate a is kind of absolute time near a given boundary of CD representing the perceptive field of a particular conscious observer and serves as a common time for all space-time surfaces in the superposition. Newton would not have been so wrong after all.

   Also adelic vision involving number theoretic arguments selects a as a unique time coordinate. In p-adic sectors of adele number theoretic universality (NTU) forces discretization since the coordinates of hyperboloid consist of hyperbolic angle and ordinary angles. p-Adicallhy one cannot realize either angles nor their hyperbolic counterparts. This demands discretization in terms of roots of unity (phases) and roots of e (exponents of hyperbolic angles) inducing finite-D extension of p-adic number fields in accordance with finiteness of cognition. a as Lorentz invariant would be genuine p-adic coordinate which can in principle be continuous in p-adic sense. Measurement resolution however discretizes also a.

   This discretization leads to tessellations of a=constant hyperboloid having interpretation in terms of cognitive representation in the intersection of real and various p-adic variants of space-time surface with points having coordinates in the extension of rationals involved. There are two choices for a. The correct choice corresponds to the passive boundary of CD unaffected in state function reductions.

3. Clearly, the vision about space-time as 4-surface of H and NTU show their predictive power. Even more, adelic physics itself might solve the problem of Lorentz invariant synchronization in terms of a clock network assignable to the nodes of tessellation!

   Suppose that tessellation defines a clock network. What synchronization could mean? Certainly strong correlations between the nodes of the network Could the correlation be due to maximal quantum entanglement (maximal at least in p-adic sense) so that the network of clocks would behave like a single quantum clock? Bose-Einstein condensate of clocks as one might say? Could quantum entanglement in astrophysical scales predicted by TGD via $h_{gr} = h_{eff} = n \times h$ hypothesis help to establish synchronized clock networks even in astrophysical scales? Could Nature guarantee Lorentz invariant synchronization automatically?

   What would be needed would be not only 3-D lattice but also oscillatory behaviour in time. This is more or less like time crystal (see `http://tinyurl.com/jbj5j68` and `http://tinyurl.com/zy73t6r`)! Time crystal like states have been observed but they require feed of energy in contrast to what Wilzek proposed. In TGD Universe this would be due to the need to generate large $h_{eff}/h = n$ phases since the energy of states with n increases with n [K8, K9, K10, K11]. In biological systems this requires metabolic energy feed. Can one imageine even cosmic 4-D lattice for which there would be the analog of metabolic energy feed?

   I have already a model for tensor networks and also here a appears naturally [K16]. Tensor networks would correspond at embedding space level to tessellations of hyperboloid $t^2 - r^2 = a^2$ analogous to 3-D lattices but with recession velocity taking the role of quantized position for the point of lattice. They would induce tessellations of space-time surface: space-time surface would go through the points of the tessellation (having also CP_2 counterpart). The number of these tessellations is huge. Clocks would be at the nodes of these lattice like structures. Maximal entanglement would be key feature of this network. This would make the clocks at the nodes one big cosmic clock.

If astrophysical objects serving as clocks tend to be at the nodes of tessellation, quantization of cosmic redshifts is predicted! What is fascinating is that there is evidence for this [E33, E43]: for TGD based model for this see [K31, K20]! Maybe dark matter fraction of Universe might have taken care of the Lorentz invariant synchronization so that we need not worry about that!

11 Does The Rate Of Cosmic Expansion Oscillate?

H. I. Ringermacher and L. R. Mead have written a very nice article (`http://tinyurl.com/oqcn2hp`) with title "Observation of discrete oscillations in a model-independent plot of cosmological scale factor versus lookback time and scalar field model" [E40]. In the following I summarize the contents of the article as I understand it. After that I consider TGD inspired model for the findings based on the assumption that dark matter corresponds to phase with gigantic values of effective Planck constant. Appendix contains summary about Gaussian Mersennes which predict correctly both cosmological, astrophysical, biological, nuclear physics, length scales and predict new important length scales in particle physics.

The claim of the article is that the time derivative of the cosmic scale parameter da/dt oscillates peroidically. When da/dt has minimum or maximum, the acceleration parameter d^2a/dt^2 of the Universe changes sign acclerating expansions changes to slowing down or vice versa. The authors have used several methods such as smoothing, fast Fourier transform and autocorrelation and they are reported to all give the same results. 3.5 sigma is mentioned as characterization of the reliability of finding: the probability that it finding is fluke would be smaller than .1 per cent if the observable value obey Gaussian distribution (`http://tinyurl.com/zp6tpr3`). For a layman it seems a miracle that the authors can extract from the chaotic looking data for da/dt a nice graph showing at least three minima and maxima.

Authors reports that the acceleration for the rate of cosmic expansion oscillates rather than being approximately constant. Instead of single transition redshift at which acceleration changes sign there are three in the region of redshifts studied. The period of oscillation in cosmic time t is deduced to be approximately .15 ($\simeq 1/7$) Hubbles times $T_H = 1/H_0 \simeq 1.4\times 10^{10}$ years= 14 aeons from the nominal value of $H_0 = 68kms^{-1}MPc^{-1}$.

The findings are explained in terms of a model of dark energy and matter. Quite generally, these models explain dark energy in terms of vacuum energy of some field. It is assumed that scalar field vacuum expectation value oscillating with frequency $f = .15H_0$ and attenuating exponentially with an attenuation coefficient $\lambda = 2.8/t(now)$, where $t(now)$ is the age of the Universe about $t(now) = 1.38\times 10^{10}$ years. The mass of the scalar field would be incredibly small - about 3×10^{-32} eV. The corresponding Compton time would be 1.3×10^{10} years and very close the age of the Universe. The model is otherwise like ΛCDM model but adds this tiny effect. Hence the constantly accelerating expansion is modified with oscillating expansion slightly deviating from from during the early cosmology.

In absence of accelerating expansion redshift z would be in good approximation linear in time. Now the situation is however nonlinear and authors deduce the relationship $t = t(z)$ allowing to express a and da/dt as functions of redshift z, which in ideal cosmic expansion is given by $z = a(now)/a(then) - 1$, where $a(now)$ and $a(then)$ are value of scale radius a now and at the moment of emission.

The model thus replaces single transition redshift with average value $z = .77$ with three transition redshifts. In fact, it has been found that Planck date differ in details from the earlier CMB data modelled rather satisfactorily in ΛCDM model.

The relative minima of da/dt were found at times $t/t(now) = 0.78$, 0.63 and 0.47 and relative maxima at times $t/t(now) = 0.87$, 0.71 and 0.56. $\Delta t/t(now) = .15$ is clearly the period. The relative minima correspond to red-shifts of $z = 0.26$, 0.51, and 0.9: note that the first two correspond to approximate periodicity with $\Delta z = .25$ but the third - the earliest minimum at which acceleration begins to corresponds to much larger redshift than one might expect. The relative maxima correspond to $z = 0.14$, 0.3, and 0.66 (in the maximum the acceleration becomes negative). The reported transition phase shifts have a rather wide distribution. The identified transition redshifts are reported to be near to those reported in literature. The wide distribution of transition redshifts shows how large the uncertainties concerning the beginning of the accelerated expanations are.

11.1 TGD Based Model For The Findings

TGD based model relies heavily on recent TGD inspired view about cosmology and general ideas of quantum TGD, in particular the possibility of dark matter quantum coherent in astrophysical and even cosmological scales.

1. p-Adic length scale hypothesis allows to make quantitative estimates and so called Gaussian Mersennes discussed in the Appendix allow to identify fundamental length and time scales covering cosmology, astrophysics, biology, nuclear physics, and particle physics. TGD based description of dark matter as a hierarchy of phases with non-standard value of Planck constant is second new element.

   (a) p-Adic length scale hypothesis leads to the vision that cosmic expansion is not smooth at the level of many-sheeted space-time but takes place as rather rapid phase transitions. Either the p-adic length scale or dark length scale characterized by the value of the effective Planck constant $h_{eff} = n \times h$ assignable to the dark matter changes. The identification $\hbar_{eff} = \hbar_{gr} = GMm/v_0$ assignable to a dark energy carrying magnetic flux tube connecting masses M and m is very attractive: v_0 is a velocity parameter characterizing the system and in the model for the planetary system has same value for inner (outer) planets [K30, K26].

   (b) For a given dark matter object no expansion would occur during the intermediate periods. For instance, it is known that solar system does not participate cosmic expansion but only comoves. I have proposed that even Earth has suffered a local variant of such a phase transition increasing its size by a factor two: Cambrian explosion in biology would relate to this transition [L18].

   (c) Critical cosmology would describe the phase transition. This model is a long length scale description of the situation in single sheeted space-time of GRT obtained by replacing the sheets of many-sheeted space-time with a slightly curved regions of Minkowski space with gravitational and other fields determined as sums of the gravitational fields and gauge potentials for the sheets [K36]. TGD inspired cosmology suggests a one parameter model for these phase transitions [K31]. This model is also behind the TGD counterpart of inflationary cosmology identified as a phase transition from cosmic string dominated phase to that in which GRT type space-time dominates. Phase transitions modellable by critical cosmology could also explain accelerated expansion considered now as occurring in much longer length and time scales.

   (d) At the deeper level magnetic flux tubes carrying monopole fluxes are carriers of dark energy as magnetic energy and of dark matter as large h_{eff} phases. No new scalar fields such as inflaton fields are introduced. The hierarchy of Planck constants can be reduced to quantum criticality of TGD Universe allowing quantification in terms of a hierarchy of algebraic extensions of rationals in number theoretic formulation of TGD [K38]. The parameters characterizing string world sheets and partonic 2-surfacs serving as "space-time genes" and continuable to space-time surfaces as preferred extremals of Kähler action in strong holography belong to these algebraic extensions forming a hierarchy and inducing corresponding extensions of p-adic number fields allowing to extend real number based physics to adelic physics.

2. Zero energy ontology brings in further new elements.

   (a) The number theoretic vision leads to the discretization of the moduli space for causal diamonds (CDs, basic element of ZEO) with second boundary fixed. Without discretization the moduli space would be hyperbolic space H^3 - cosmic time $a = constant$ section of future directed lightcone. Note that a corresponds to the scale factor $a(t)$ in TGD based cosmology. Discretization of H^3 is necessary and is obtained as a tessellation by identifying the points related by a infinite discrete sub-group H of $SL(2,C)$. The counterpart of lattice cell is H_3 coset defining hyperbolic manifold. The causal diamonds crucial for zero energy ontology have discrete wave function in this space. This suggests a lattice like structures in the sense that position of a physical system defined by the non-fixed top of corresponding CD has discrete position in the lattice defined by the action of the subgroup H. In ordinary 3-D lattices position is quantized. Now the direction of recession velocity and the hyperbolic angle defining the redshif-tassociated with the corresponding astrophysical objects is quantized. Note that the redshift characterized the position only if the object is co-moving.

(b) Also the tessellation of second light-like boundary of causal diamond (CD) defines discrete moduli space identifiable as the orbit of discrete subgroup H: this tessellation would be limiting case of that for hyperbolic 3-space. In this case the lattice like structure would be physical and realized at space-time level. The positions of partonic 2-surfaces would form lattice like structure at the light-like boundary. Biology suggests that dark flux tubes form a grid like structure analogous to coordinate grid. For instance, in TGD based model galaxies are like pearls in the necklace formed by a flux tube. The dynamics of this dark lattice like structure would make it visible itself in the behavior of the visibile matter.

There is a strong temptation to think that the dark matter can form lattice like structures at the light-like boundary of CD. And these structures would expand in stepwise manner by rapid quantum phase transitions. This because dark matter could be quantum coherent in cosmological length scales.

(c) Adelic physics [K38] allows to consider a concrete prediction for the unit of quantized cosmic redhifts if astrophysical objects form tessellations of light-cone boundary and even H^3 in cosmic scales. The basic unit appearing in the exponent defining the Lorentz boost would depend on the algebraic extension involved and of p-adic prime defining effective p-adicity and would be $e^{\eta} = e^{k/np}$, $0 \leq k < np$. The hyperbolic "phase" relates by by the standard formula to the redshift: $1 + z = e^{\eta} = e^{k/np}$. The relationship to the cosmic recession velocity $\beta = v/c$ is obtained from $exp(\eta) = \gamma \times (1+\beta) = \sqrt{(1+\beta)/(1-\beta)}$, $\gamma = 1/\sqrt{1-\beta^2}$: $\beta = (exp(2\eta)-1)/(exp(2\eta)+1) = (exp(2k/np)+1)/(exp(2k/np)-1) \simeq k/np$. The recession velocity v is approximately quantized in multiples of $v_0 = c/np$. This formula for redshifts would hold true if cosmic expansion is the sole reason for the redshift and matter is concentrated at lattice points. The obvious question is whether the transition redshifts correspond to lattice points with constant red-shift difference in the first approximation. There indeed exist support for the quantization of redhifts [E43, E33]. As shown in [K39] [L6] the discretization at the level of moduli space of CDs could have direct connection with quantum groups describing finite measurement resolution at quantum level.

3. One cannot avoid bringing in TGD inspired theory of consciousness when one speaks about quantum phase transitions in ZEO [K37, K2].

   (a) ZEO based theory of quantum measurement defines a theory of consciousness and leads rather straightforwardly to the identification of the quantum physical correlates for the notion of self [K29, K2, K37]. These quantum phase transitions could correspond to state function reductions to the opposite boundary of CD following a sequence of reductions at fixed boundary (analog of repeated quantum measurement giving rise to Zeno effect). The reduction to opposite boundary would mean change of the arrow of time for CD in the scale considered: recall that CDs form a hierarchy and the arrow of time changes for dark matter.

   (b) Could the phase transitions changing the size scale of the lattice be this kind of phase transitions? It seems clear that if state function reductions at opposite boundary occur in cosmic scale, it must be followed rather rapidly by a phase transition bringing back the original arrow of time since otherwise the cosmology would become time reversed. Could the arrow of time associated with a larger CD force define standard arrow of time and force a rapid return to it for sub-CDs?

The following model for cosmic expansion as rapid phase transitions followed by damped oscillations suggests itself.

1. Dark matter lattice would not expand smoothly but by phase transitions in which the scale of the lattice would increase by a power of two (one cannot exclude $\sqrt{2}$ and in principle even powers of p or $\sqrt{p}$ must be considered). This could be interpreted as an increase of p-adic length scale or of effective Planck contant by factor 2. The subgroup H defining the lattice cell might change and the standard wisdom about phase transitions suggests that symmetry breaking to subgroup occurs. Super-symplectic algebra allows infinite hierarchy of sub-algebras isomorphic to with conformal weights coming as multiples of those for the entire algebra so that one has fractality: symmetry breaking without symmetry breaking. Same symmetry appears in larger scale defined by the new value of h_{eff}.

2. During the phase transitions rapid acceleration would occur and z would be larger than predicted by the models with smooth expansion. The authors indeed find that the earliest transition redshift is unexpectedly large. These transitions would be followed by lattice oscillations inducing the oscillations of da/dt too.

3. Visible matter would comove in the background defined by dark matter and would respond to dark matter phase transitions in cosmic scale in induced dynamics with additional anomalous expansion lasting the duration of dark matter phase transition. Comoving property means for visible matter means that in the scale of CD involved visible matter does not expand during the intermediate periods. This is known to be the case for solar system.

4. As found, the claimed transition redshifts correspond to scalings of a by factor smaller 2, which suggests that they three cycles (also fourth could be included in the model of authors) do not correspond to separate phase transitions but to single phase transition followed by an oscillation as in the proposed model. Time value t assigned to the three minima and maxima of da/dt are evenly spaced in good approximation.

   Number theoretical quantization for the exponents of the hyperbolic angles (analogous to phases) gives $z = exp(k/np) - 1$, $k = 1, ..., np - 1$ if no other sources of redshifts are present. If there are four minima within octave of a/a_0, one must have $p = 2$ and $n = 2$: both values are very natural. In this case the linear approximation for z is not good. The kinematical redshifts for the minima would be $z \in \{.28, .65, 1.12)\}$: note that the ratios of $1+z$ factors remain below 2. The reported redshifts for the minima are $z \in \{0.26, 0.51, 0.9\}$ smaller. There seems to be a contribution reducing the redshifts from their kinematical values: this contribution could come from a lattice oscillation partially compensating the comoving accelerated expansion and bringing acceleration to zero and at the same time reducing the expansion rate and thus also z.

A possible criticism of the model is the introduction of dark matter lattice replacing the scalar field of [E40] with oscillating vacuum expectation value. The observed redshift quantization could be used to defend this assumption. Quantum coherence in cosmological scales of course raises the eyebrows of the standard physicist but the recent fashion in which wormholes are assumed to connect blackholes and give rise to quantum coherence is consistent with this picture, which an be seen as a GRT adaptation of TGD vision in which magnetic flux tubes replace wormholes and partonic 2-surfaces replaced blackhole horizons and space-time regions having Euclidian signature of induced metric serving as lines of generalized Feynman diagrams replace blackhole interiors.

11.2 Appendix: P-Adic Length Scale Hypothesis And Gaussian Mersennes

The proposed model does not say much about p-adic primes important in cosmology. The following arguments demonstrate as a by-product that Gaussian Mersennes define p-adic length scales having identification as fundamental length scales both in cosmology and astrophysics. The largest Gaussian Mersenne defines slightly longer time scale than the age of the Universe appearing as the parameter in the model for oscillations and this Gaussian Mersenne could explain why just this time scale appears. What is remarkable the age of the Universe would correspond to a length scale analogous to length scales fundamental in TGD inspired quantum biology and one can wonder whether this has a deeper meaning. What is also remarkable, that the p-adic Compton lengths for dark electron define the fundamental scales. Does this mean that dark electrons or their p-adically scaled down variants are important in all these scales?

p-Adic length scale hypothesis states that primes slightly below powers of two are physically preferred ones. Mersenne primes $M_n = 2^n - 1$ obviously satisfy this condition optimally. The proposal generalizes to Gaussian Mersenne primes $M_{G,n} = (1+i)^n - 1$ (`http://tinyurl.com/pptxe9c`). It is now possible to understand preferred p-adic primes as so called ramified primes of an algebraic extension of rationals to which the parameters characterizing string world sheets and partonic 2-surfaces belong. Strong form of holography is crucial: space-time surfaces are constructible from these 2-surfaces: for p-adic variants the construction should be easy by the presence of pseudo-constants. In real sector very probably continuation is possible only in special cases. The interpretation would be that some space-time surfaces can be imagined but not realized [K24]. For certain extensions the number of realizable imaginations could be exceptionally large. These extensions would be winners in the number theoretic fight for survivalandcorresponding ramified primes would be preferred p-adic primes.

In the framework of consciousness theory the interpretation is that in this case imaginations (p-adic space-time surfaces) are realizable. Also p-adic length scale hypothesis can be understood and generalizes: primes near powers of any prime are preferred.

The definition of p-adic length scale is a convention to some degree.

1. One possible definition for L_p is as Compton length for the smallest mass possible in p-adic thermodynamics for a given prime if the first order contribution is non-vanishing.

2. Second definition is the Compton length $L_{p,e}$ for electron if it would correspond to the prime in question: in good approximation one has $L_p = \sqrt{5} \times L_{p,e}$ from p-adic mass calculations. If p-adic length scale hypothesis is assumed ($p \simeq 2^k$) one has $L_{p,e} \equiv L(k,e) = 2^{(k-127)/2} L_e$, where L_e is electron Compton length (electron mass is .5 MeV). If one is interested in Compton time $T(k,e)$, one obtains it easily from electrons Compton time .1 seconds (defining fundamental biorhythm) as $T(k,e) = 2^{(k-2*127)/2} \times .1$ seconds. I will mean with p-adic length scale $T(k,e) \simeq \sqrt{5}T(k)$ in the following.

Mersenne primes $M_n = 2^n - 1$ are as near as possible to power of two and are therefore of special interest.

1. Mersenne primes corresponding to $n \in \{2, 3, 5, 7, 13, 17, 19, 31, 61\}$ are out of reach of recent accelerators.

2. $n = 89$ characterizes weak bosons and suggests a scaled up version of hadron physics which should be seen at LHC. There are already several indications for its existence.

3. $n = 107$ corresponds to hadron physics and tau lepton.

4. $n = 127$ corresponds to electron. Mersenne primes are clearly very rare and characterize many elementary particle physics as well as hadrons and weak bosons. The largest Mersenne prime which does not define completely super-astrophysical p-adic length scale is M_{127} associated with electron.

Gaussian Mersennes (complex primes for complex integers) are much more abundant and in the following I demonstrate that corresponding p-adic time scales might seem to define fundamental length scales of cosmology, astrophysics, biology, nuclear physics, and elementary physics. I have not previously checked the possible relevance of Gaussian Mersennes for cosmology and for the physics beyond standard model above LHC energies: there are as many as 10 Gaussian Mersennes besides 9 Mersennes above LHC energy scale suggesting a lot of new physics in sharp contrast with the GUT dogma that nothing interesting happens above weak boson scale- perhaps copies of hadron physics or weak interaction physics. The list of Gaussian Mersennes is following.

1. $n \in \{2, 3, 5, 7, 11, 19, 29, 47, 73\}$ correspond to energies not accessible at LHC. $n = 79$ might define new copy of hadron physics above TeV range -something which I have not considered seriously before. The scaled variants of pion and proton masses (M_{107} hadron physics) are about 2.2 TeV and 16 TeV. Is it visible at LHC is a question mark to me.

2. $n = 113$ corresponds to nuclear physics. Gaussian Mersenne property and the fact that Gaussian Mersennes seem to be highly relevant for life at cell nucleus length scales inspires the question whether $n = 113$ could give rise to something analogous to life and genetic code. I have indeed proposed realization of genetic code and analogs of DNA, RNA, amino-acids and tRNA in terms of dark nucleon states.

3. $n = 151, 157, 163, 167$ define 4 biologically important scales between cell membrane thickness and cell nucleus size of 2.5 μm. This range contains the length scales relevant for DNA and its coiling.

4. $n = 239, 241$ define two scales $L(e, 239) = 1.96 \times 10^3$ km and $L(e, 241) = 3.93 \times 10^3$ km differing by factor 2. Earth radius is 6.3×10^3 km, outer core has radius 3494 km rather near to L(2,241) and inner core radius 1220 km, which is smaller than 1960 km but has same order of magnitude. What is important that Earth reveals the two-core structure suggested by Gaussian Mersennes.

5. $n = 283$: $L(283) = .8 \times 10^{10}$ km defines the size scale of a typical star system. The diameter of the solar system is about $d = .9 \times 10^{10}$ km.

6. $n = 353$: $L(353, e) = 2.1$ Mly, which is the size scale of galaxies. Milky Way has diameter about .9 Mly.

7. $n = 367$ defines size scale $L(267, e) = 2.8 \times 10^8$ ly, which is the scale of big voids.

8. $n = 379$: The time scale $T(379, e) = 1.79 \times 10^{10}$ years is slightly longer than the recently accepted age of the Universe about $T = 1.38 \times 10^{10}$ years and the nominal value of Hubble time $1/H = 1.4 \times 10^{10}$ years. The age of the Universe measured using cosmological scale parameter $a(t)$ is equal to the light-cone proper time for the light-cone assignable to the causal diamond is shorter than t.

For me these observations are shocking and suggest that number theory is visible in the sructure of entire cosmos. Standard skeptic of course labels all this as numerology. Only understood fact is fact. TGD indeed allows to understand these facts.

12 Correlated Triangles and Polygons in Standard Cosmology and in TGD

Peter Woit had an interesting This Week's Hype (see `http://tinyurl.com/hmmj9bp`). The inspiration came from a popular article in Quanta Magazine (see `http://tinyurl.com/jhd5xpe`) telling about the proposal of Maldacena and Nima Arkani-Hamed that the temperature fluctuations of cosmic microwave background (CMB) could exhibit deviation from Gaussianity in the sense that there would be measurable maxima of n-point correlations in CMB spectrum as function of spherical angles. These effects would relate to the large scale structure of CMB. Lubos Motl wrote about the article in different and rather aggressive tone (see `http://tinyurl.com/zzwt6ou`).

The article in Quanta Magazine does not go into technical details but the original article of Maldacena and Arkani-Hamed [B14] (see `http://tinyurl.com/ych26gcm`) contains detailed calculations for various n-point functions of inflaton field and other fields in turn determining the correlation functions for CMB temperature. The article is technically very elegant but the assumptions behind the calculations are questionable. In TGD Universe they would be simply wrong and some habitants of TGD Universe could see the approach as a demonstration for how misleading the refined mathematics can be if the assumptions behind it are wrong.

It must be emphasized that already now it is known and stressed also in [B14] that the deviations of the CMB from Gaussianity are below recent measurement resolution and the testing of the proposed non-Gaussianities requires new experimental technology such as 21 cm tomography [B11] (see `http://tinyurl.com/y7j9p35j`) mapping the redshift distribution of 21 cm hydrogen line to deduce information about fine details of CMB now n-point correlations.

Inflaton vacuum energy is in TGD framework replaced by Kähler magnetic energy and the model of Maldacena and Arkani-Hamed does not apply. The elegant work of Maldacena and

Arkani-Hamed however inspired a TGD based consideration of the situation but with very different motivations. In TGD inflaton fields do not play any role since inflaton vacuum energy is replaced with the energy of magnetic flux tubes. The polygons also appear in totally different manner and are associated with symplectic invariants identified as Kähler fluxes, and might relate closely to quantum physical correlates of arithmetic cognition. These considerations lead to a proposal that integers $(3,4,5)$ define what one might called *additive primes* for integers $n \geq 3$ allowing geometric representation as non-degenerate polygons - prime polygons. On should dig the enormous mathematical literature to find whether mathematicians have proposed this notion - probably so. Partitions would correspond to splicings of polygons to smaller polygons.

These splicings could be dynamical quantum processes behind arithmetic conscious processes involving addition. I have already earlier considered a possible counterpart for conscious prime factorization in the adelic framework [L14]. This will not be discussed in this section since this topic is definitely too far from primordial cosmology. The purpose of this article is only to give an example how a good work in theoretical physics - even when it need not be relevant for physics - can stimulate new ideas in completely different context [L12].

12.1 Could cosmic microwave background exhibit non-local correlations?

It is good to start by summarizing my understanding about the basic ideas in the work of Maldacena and Arkani-Hamed [B14] (see `http://tinyurl.com/ych26gcm`). Besides inflationary scenario the existence of very massive particles with mass of the order of inverse Hubble radius during inflationary period or even before it are assumed. They would correspond to massive excitations of superstrings. These very massive particles would decay to inflatons and these couplings would make possible non-trivial $n > 2$ point correlation functions for inflaton field. These correlations would in turn be inherited by the cosmic energy density and thus correlation functions of CMB temperature. There would be a tendency for the appearance of triangles and higher polygons for which maximum for the modulus of the n-point correlator and the hope would be that these maxima could be detected some day in CMB spectrum.

The correlation functions are calculated in de-Sitter background - e de-Sitter space is a good model for inflationary period and one can use the symmetries of de-Sitter space to make rather detailed conclusions about the general form of correlation functions.

One has only 3-D translational invariance since time translation is not isometry of de-Sitter space. By this symmetry one can perform Fourier transformation and n-point correlation functions in momentum space vanish only at points in which the sum of momenta vanishes. Momenta therefore define a closed polygon - triangle, square, etc... in momentum space. Besides 3-D translational invariance there is also 3-D conformal invariance. As in the case of 2-D conformal invariance, one can deduce the general form of lowest n-point functions highly uniquely for any spin (string excitations can have arbitrarily high spin) in both momentum space and x-space.

There is analogy analogy to what particle theorists are doing at LHC: in this case four-momentum conservation gives similar constraint and define polygons in four-momentum space. The correlation functions of fields define the scattering amplitudes. In cosmology one is interested on extracting non-trivial n-point correlations from the background. These special configurations would correspond to squeezed triangles. At LHC final state particles with very large transversal momentum would be an analogous source of information.

One could say that inflationary period defines a cosmic particle accelerator and that the scatterings, which have taken near to the end of the inflationary period are visible in CMB: this because the exponential expansion would have destroyed the memories about earlier times. The cosmic particle experiment would end, when inflationary period ends. From the graph of Wikipedia article (see `http://tinyurl.com/odlpyg8`) one learns that this would correspond to Hubble radius $1/H$ of order $1/H = 10^{-25}$ meters so that the mass of the massive string excitations would be larger than mass of about $H_{min} \sim 10^{10} \times m_p$ or about 10^{-9} Planck masses.

The article in Quanta Magazine suggests that the triangles correspond to triplets of hot spots in CMB: maybe this follows from the assumption that the modulus correlation function is maximum. I do not quite understand this. There is correlation between values of temperature but this does not imply that temperature at the hot spots would be higher and same. It is mentioned that the so called cosmic fluctuations might make it impossible to detect these basically quantal correlations.

12.2 Early cosmology in TGD framework

In TGD framework polygons interpreted in terms of enhanced correlations of inflaton field do not appear in cosmology since inflaton field is not needed. Momentum conservation gives rise to polygons also now but they will not be considered in the sequel. In TGD framework the physical picture is very different although inflation has TGD analog and also causal diamonds (CDs) serving as key geometric element of Zero Energy Ontology (ZEO) are bring in mind Big Bang followed by Big Crunch.

1. The starting point is the fact cosmic temperature is constant with variations of order $\Delta T/T \sim 10^{-5}$. Inflationary theory was born to explain this miracle in terms of exponential expansion destroying all details of the primordial temperature distribution.

2. Also in TGD framework the analog for the exponential expansion is predicted but it would not be needed to explain the constancy of the temperature as resulting of smoothing out of fluctuations. Temperature fluctuations would reduce to fluctuations for the beginning of the transition to the radiation dominated phase.

   The primordial state preceding the TGD analog of inflationary period would be gas of cosmic strings having arbitrarily long lengths and form a fractal structure - this is new and makes sense because the size of horizon is infinite in M^4. Cosmic strings could serve as correlates for quantum entanglement and an elegant explanation for the constancy of temperature would be in terms of quantum coherence in cosmic length scales involving negentropic entanglement (NE) and hierarchy of Planck constants $h_{eff} = n \times h$. This together with Zero Energy Ontology (ZEO) leads to a TGD analog of the cyclic cosmology with entire cosmos regarded as conscious entity [K31] [L9]. In the cyclic cosmology the cosmic strings near the boundary of CD would not be any more free cosmic strings but magnetic flux tubes and every period of cycle would make them thicker so that genuine evolution would take place instead of boring repetition.

   The analog of the inflationary period corresponds to a creation of space-time in GRT sense. Space-time sheets with 4-D M^4 projection are generated and gas of cosmic strings topologically condensed at them and starts (or continues) transformation to (thicker) magnetic flux tubes. In other words, 2-D M^4 projection (string world sheet) begins to grow in thickness. Ordinary matter emerges from the decay of the magnetic energy of cosmic string to ordinary particles during this period and the analog of inflationary cosmology would describe this matter (it is not quite clear whether also the energy of topologically condensed cosmic strings is included).

3. The magnetic energy density of flux tubes replaces the vacuum energy density of inflaton fields in TGD framework. The massive particles (string excitations) decaying to inflatons correspond to topologically condensing cosmic strings carrying conserved monopole flux. Their magnetic energy decays to particles as their thickness grows and magnetic field strength and therefore also magnetic energy density per unit length is reduced.

   Magnetic flux tubes would be present also in the recent cosmology and form basic building bricks of various astrophysical structures. For instance, galaxies would be string like objects, which are like pearls in a necklace formed by long string like objects at the boundaries of large voids. The sensational news would be that the primordial stringy structures are directly visible in the recent cosmology and seen long time ago! No statistical description is needed and if possible it must take into account the fractality realized in terms of p-adic length scale hierarchy and hierarchy of Planck constants, which is of course one of the predictions.

4. TGD suggests a model for the transition from the gas of cosmic strings to the radiation dominated cosmology as Robertson-Walker cosmology in terms of vacuum extremal having interpretation as critical or over-critical cosmology in GRT framework [K31]. This cosmology is unique apart from its finite duration. Mass density approaches infinite value before a transition to Euclidian signature of induced metric would happen (TGD interpretation could be in terms of TGD analog of blackhole). The condition that the energy density of space-time surface does not exceed that of cosmic strings in M^4 implies that the transition to radiation dominated cosmology takes place already earlier.

This cosmology would replace the de-Sitter cosmology in the model of Maldacena and Arkani-Hamed if the notion of inflaton field would make sense. The critical cosmology has flat 3-space and in this case one could apply momentum conservation but energy conservation would not apply. The conservation law of 3-momentum applies at space-time level and should not be confused with the fundamental conservation of four-momentum at embedding space level. QFT at space-time level would be at best an approximation. The modes of quantum fields are replaced with spinor harmonics of embedding space defining ground state of the super-symplectic representations and one cannot neglect this algebra in the fundamental description using scattering amplitudes coded by zero energy states representable as modes of spinor fields of WCW.

5. The fractal structure of cosmic string condensate implies the failure of QFT description based on point like particles described by inflaton field. Strong form of holography (SH) states that string world sheets and partonic 2-surfaces serve as "space-time genes". This would suggests that string model in many-sheeted space-time could provide a fundamental description for the topological condensation and decay of cosmic strings to ordinary particles. The "space-time half" (or bulk half) of SH conforms with the idea that the cosmic strings are still there as magnetic flux tubes serving as building bricks of directly observed astrophysical and cosmological structures. For instance, galactic dark matter could be identified as magnetic energy of the long string like object defining the cosmic necklace with galaxies as pearls.

12.3 How do polygons emerge in TGD framework?

The duality defined by strong form of holography (SH) has 2 sides. Space-time side (bulk) and boundary side (string world sheets and partonic 2-surfaces). 2-D half of SH would suggest a description based on string world sheets and partonic 2-surfaces. This description should be especially simple for the quantum states realized as spinor fields in WCW ("world of classical worlds"). The spinors (as opposed to spinor fields) are now fermionic Fock states assignable to space-time surface defining a point of WCW. TGD extends ordinary 2-D conformal invariance to super-symplectic symmetry applying at the boundary of light-cone: note that given boundary of causal diamond (CD) is contained by light-cone boundary.

1. The correlation functions at embedding space level for fundamental objects, which are fermions at partonic 2-surfaces could be calculated by applying super-symplectic invariance having conformal structure. I have made rather concrete proposals in this respect. For instance, I have suggested that the conformal weights for the generators of supersymplectic algebra are given by poles of fermionic zeta $\zeta_F(s) = \zeta(s)/\zeta(2s)$ and thus include zeros of zeta scaled down by factor 1/2 [K12]. A related proposal is conformal confinement guaranteeing the reality of net conformal weights.

2. The conformally invariant correlation functions are those of super-symplectic CFT at light-cone boundary or its extension to CD. There would be the analog of conformal invariance associated with the light-like radial coordinate r_M and symplectic invariance associated with CP_2 and sphere S^2 localized with respect to r_M analogous to the complex coordinate in ordinary conformal invariance and naturally continued to hypercomplex coordinate at string world sheets carrying the fermionic modes and together with partonic 2-surfaces defining the boundary part of SH.

Symplectic invariants emerge in the following manner. Positive and negative energy parts of zero energy states would also depend on zero modes defined by super-symplectic invariants and this brings in polygons. Polygons emerge also from four-momentum conservation. These of course are also now present and involve the product of Lorentz group and color group assignable to CD near its either boundary. It seems that the extension of Poincare translations to Kac-Moody type symmetry allows to have full Poincare invariance (in its interior CD looks locally like $M^4 \times CP_2$).

1. One can define the symplectic invariants as magnetic fluxes associated with S^2 and CP_2 Kähler forms. For string world sheets one would obtain non-integrable phase factors. The vertices of polygons defined by string world sheets would correspond to the intersections of

the string world sheets with partonic 2-surfaces at the boundaries of CD and at partonic 2-surfaces defining generalized vertices at which 3 light-like 3-surfaces meet along their ends.

2. Any polygon at partonic 2-surface would also allow to define such invariants. A physically natural assumption is that the vertices of these polygons are realized physically by adding fermions or antifermions at them. Kähler fluxes can be expressed in terms of non-integrable phase factors associated with the edges. This assumption would give the desired connection with quantum physics and fix highly uniquely but not completely the invariants appearing in physical states.

The correlated polygons would be thus naturally associated with fundamental fermions and a better analogy would be negentropically entangled n-fermion state rather than corresponding to maximum of the modulus of n-point correlation function. Hierarchy of Planck constants makes these states possible even in cosmological scales. The point would be that negentropic entanglement assignable to the p-adic sectors of WCW would be in key role.

12.4 Symplectic invariants and Abelian non-integrable phase factors

Consider now the polygons assignable to many-fermion states at partonic 2-surfaces.

1. The polygon associated with a given set of vertices defined by the position of fermions is far from unique and different polygons correspond to different physical situations. Certainly one must require that the geodesic polygon is not self-intersecting and defines a polygon or set of polygons.

2. Geometrically the polygon is not unique unless it is convex. For instance, one can take regular n-gon and add one vertex to its interior. The polygon can be also constructed in several ways. From this one obtains a non-convex $n+1$-gon in $n+1$ ways.

3. Given polygon is analogous with Hamiltonian cycle connecting all points of given graph. Now one does not have graph structure with edges and vertices unless one defines it by nearest neighbor property. Platonic solids provide an example of this kind of situation. Hamiltonian cycles [A4, A18] are key element in the TGD inspired model for music harmony leading also to a model of genetic code [K28] [L5].

4. One should somehow fix the edges of the polygon. For string world sheets the edges would be boundaries of string world sheet. For partonic 2-surfaces the simplest option is that the edges are geodesic lines and thus have shortest possible length. This would bring in metric so that the idea about TGD as almost topological QFT would be realized.

One can distinguish between two cases: single polygon or several polygons.

1. One has maximal entanglement between fundamental fermions, when the vertices define single polygon. One can however have several polygons for a given set of vertices and in this case the coherence is reduced. Minimal correlations correspond to maximal number of 3-gons and minimal number of 4-gons and 5-gons.

2. For large $h_{eff} = n \times h$ the partonic 2-surfaces can have macroscopic and even astrophysical size and one can consider assigning many-fermion states with them. For instance, anyonic states could be interpreted in this manner. In this case it would be natural to consider various decompositions of the state to polygons representing entangled fermions.

The definition of symplectic invariant depends on whether one has single polygon or several polygons.

1. In the case that there are several polygons not containing polygons inside them (if this the case,then the complement of polygon must satisfy the condition) one can uniquely identify the interior of each polygon and assign a flux with it. Non-integrable phase factor is well-defined now. If there is only single polygon then also the complement of polygon could define the flux. Polygon and its complement define fluxes Φ and $\Phi_{tot} - \Phi$.

2. If partonic 2-surface carries monopole Kähler charge Φ_{tot} is essentially $n\pi$, where n is magnetic monopole flux through the partonic 2-surface. This is half integer - not integer: this is key feature of TGD and forces the coupling of Kähler gauge potential to the spinors leading to the quantum number spectrum of standard model. The exponent can be equal to -1 for half-odd integer.

   This problem disappears if both throats of the wormhole contact connecting the space-time sheets with Minkowski signature give their contribution so that two minus-signs give one plus sign. Elementary particles necessarily consist of wormhole contacts through which monopole flux flows and runs along second space-time sheet to another contact and returns along second space-time sheet so that closed monopole flux tube is obtained. The function of the flux must be single valued. This demands that it must reduce to the cosine of the integer multiple of the flux and identifiable as as the real part of the integer power of magnetic flux through the polygon.

The number theoretically deepest point is geometrically completely trivial.

1. Only $n > 2$-gons are non-degenerate and 3-, 4- and 5-gons are prime polygons in the sense that they cannot be sliced to lower polygons. Already 6-gon decomposes to 2 triangles.

2. One can wonder whether the appearance of 3 prime polygons might relate to family replication phenomenon for which TGD suggests an explanation in terms of genus of the partonic 2-surface [K5]. This does not seem to be the case. There is however other three special integers: namely 0,1, and 2.

   The connection with family replication phenomenon could be following. When the number of handles at the parton surface exceeds 2, the system forms entangled/bound states describable in terms of polygons with handles at vertices. This would be kind of phase transition. Fundamental fermion families with handle number 0,1,2 would be analogous to integers 0,1,2 and the anyonic many-handle states with NE would be analogous to partitions of integers $n > 2$ represented by the prime polygons. They would correspond to the emergence of p-adic cognition. One could not assign NE and cognition with elementary particles but only to more complex objects such as anyonic states associated with large partonic 2-surfaces (perhaps large because they have large Planck constant $h_{eff} = n \times h$) [K27].

The identification of prime polygons as geometric representations of "additive primes" for integers $n > 2$ is a number theoretically fascinating idea and the possible connection with the realization of arithmetic consciousness is equally interesting idea to consider but because this would take too far from primordial cosmology it is better to leave this topic to another article [L12].

13 Cosmology in crisis

Standard cosmology is in crisis. There are a lot of anomalies but two of them have received special attention recently. The most recent anomaly is due to the findings that the so called lensing amplitude in CMB is larger than ΛCDM predicts [E14]. This suggest that the density of the Universe is 5 per cent higher than the critical density so that Universe should closed rather than flat and infinite. Second anomaly is old: depending on measurement method one obtains two values for the Hubble constant differing remarkably. The debate about this has continued for decades and continues still.

These anomalies and many other suggest that something is wrong with - not only the assumptions of GRT based cosmology - but with Einsteinian space-time. TGD indeed predicts new view about space-time. Space-time at fundamental level is identified as 4-D surface in 8-D $M^4 \times CP_2$. The resulting many-sheeted space-time is locally extremely simple but has non-trivial topology in all scales. The M^4 projection of space-time regions can have dimension $D \leq 4$. For $D = 4$ one can speak of Einsteinian space-time. Non-Einsteinian configurations such as CP_2 type extremals $D = 1$ representing elementary particles and cosmic strings with$D = 2$ play central role in TGD Universe in all scales. For $D < 4$ the dimension of projection is topologically unstable and cosmic strings thicken to flux tubes. GRT space-time is obtained by taking into account only the Einsteinian spacetime surfaces at QFT-GRT limit but one expects that this is not enough: cosmic strings bring in new effects not present in typical GRT cosmology.

In this section the two above mentioned problems classified as crises are discussed in terms of TGD view about space-time.

13.1 Is 3-space closed or flat and infinite?

ΛCMD model (see `http://tinyurl.com/z8z8ulu`) provides the standard model for cosmology model assumes flat 3-space cold dark matter realized in terms of dark matter halos at galactic level. Cosmological constant Λ parameterizes dark energy density. The gives a rather satisfactory description of the CMB data in terms of 6 parameter but there are however some anomalies. There deviations from the predictions from the actual CMB data. The problems related to the notions of dark matter and energy itself are at deeper levels.

Now a new problem - even crisis - has emerged (I have the feeling that it has been always in crisis). There is evidence that 3-space is actually closed rather than flat and infinite! But 3-space cannot be both simultaneously.

13.1.1 Findings

Alessandro Melchiorri of Sapienza University of Rome Eleonora di Valentino of the University of Manchester and Joseph Silk, principally of the University of Oxford, published in Nature Astronomy a paper "*Planck evidence for a closed Universe and a possible crisis for cosmology*" [E14] (see `http://tinyurl.com/y5q55ds3`). Here is the abstract of the article.

The recent Planck Legacy 2018 release has confirmed the presence of an enhanced lensing amplitude in cosmic microwave background power spectra compared with that predicted in the standard Λ cold dark matter model, where Λ is the cosmological constant.

A closed Universe can provide a physical explanation for this effect, with the Planck cosmic microwave background spectra now preferring a positive curvature at more than the 99 per cent confidence level.

Here, we further investigate the evidence for a closed Universe from Planck, showing that positive curvature naturally explains the anomalous lensing amplitude, and demonstrating that it also removes a well-known tension in the Planck dataset concerning the values of cosmological parameters derived at different angular scales. We show that since the Planck power spectra prefer a closed Universe, discordances higher than generally estimated arise for most of the local cosmological observables, including baryon acoustic oscillations. The assumption of a flat Universe could therefore mask a cosmological crisis where disparate observed properties of the Universe appear to be mutually inconsistent. Future measurements are needed to clarify whether the observed discordances are due to undetected systematics, or to new physics or simply are a statistical fluctuation.

A lensing amplitude 5 per cent larger than expected is observed. Concretely this means following.

1. Gravitational lensing (see `http://tinyurl.com/c3n6b8g)`) is essentially scattering of the incoming light in the gravitational field of matter between the detector an sources so that for a single object between the source the light seems to becoming from a circular object rather than point like object.

2. The light of CMB entering detector has experienced large number of lensings and the images of various features in the data become blurred. The larger the lensing, the more blurred the object image. Lensing amplitude is proportional to the curvature of 3-space and if the curvature vanishes as in flat cosmology, lensing amplitude should be very small and due to fluctuations. There should be for other reasons.

3. ΛCDM predicts flat 3-space so that the observed lensing is anomaly if indeed real effect. The obvious explanation would be that the density of matter is about 5 per cent higher than the model predicts. The density would become overcritical and the infinite flat 3-space would close to sphere. This would be a dramatic change in the topology of 3-space.

As the abstract tells, positive curvature would also remove the well-known tension in the Planck dataset concerning the values of cosmological parameters derived at different angular scales.

There are however objections. For instance, inflation theory favours infinite 3-space. There is also second manner to deduce 3-curvature. Lensing reconstruction measures correlations from sets of four points in the sky to deduce 3-curvature. The results are in accordance with flatness.

Various empirical inputs force flat 3-space so that one cannot just add to ΛCDM the curvature as 7:th parameter. For instance, it would very difficult to understand how this modification could be consistent with inflation theory involving flat expanding Universe. Therefore one can say that cosmology is in crisis.

13.1.2 What says TGD?

Something new is needed. Hyperbolic or flat Universe seems to be a natural assumption in TGD framework assuming that at fundamental level space-times are surfaces in $M^4 \times CP_2$.

1. General Relativity emerges as a long length scale approximation in which space-time surfaces are assumed to be Einsteinian in long scale, that is having 4-D M^4 projection. There are also non-Einsteinian space-time surfaces. CP_2 type extremals with 1-D light geodesic as M^4 projection, and string like objects with 2-D M^4 projection.

2. Cosmic strings are basic entities of the primordial cosmology in TGD Universe and have 2-D M^4 projection as string world sheets: there is no Einsteinian space-time and it emerges during the TGD analog of the inflationary period [K31, K20]. Cosmic strings are unstable against thickening of the $M4$ projection of cosmic strings so that they tend to thicken to flux tubes. Cosmic strings and flux tubes are present also during the Einsteinian era. One can speak of topological condensation of cosmic strings to space-time surface. In GRT based cosmology these objects have no counterpart.

   Cosmic strings appear in two varieties depending on whether the quantizes magnetic flux associated with their closed cross section is monopole flux or not (vanishes). What is important that monopole fluxes require no currents, which solves several problems of cosmology and astrophysics. One example is the presence of magnetic fields in cosmic length scales, stability of the Earth's magnetic field [L7] and the present strange findings about the magnetic field of Mars [L22].

3. The model for the formation of various astrophysical objects [L20, L24, L25] relies on the thickening of cosmic string portions to monopole flux tubes. One must therefore include them. In accordance with the notion of many-sheeted space-time, cosmology must be replaced with a fractal hierarchy of cosmologies with length scale dependent parameters such as cosmological constant [L10].

   Remark: String world sheets appear also as singularities of space-time surfaces as minimal surfaces appearing as extremals of also 4-D Kähler action obtained as a dimensional reduction of the twistor lift of 4-D Kähler action. These strings are like edges of 3-space at which tangent space-time dimension of space-time surface is 2 instead of 4.

4. Cosmic strings carry dark energy and dark matter. Dark energy is sum of magnetic and volume contributions. The latter is proportional to cosmological constant Λ, which depends on the size scale of the space-time sheets and comes in some negative powers of 2 corresponding to preferred p-adic length scales. Λ_{CDM} would correspond to length scale for space-time sheets of order recent size of cosmos.

In this framework the most recent crisis of cosmology would reflect the failure of the Einsteinian space-time concept basically due to the existence of cosmic strings and other objects with lower-D projection.

The observed too large lensing amplitude is intuitively easy to understand in terms of cosmic strings. The incoming CMB photon would express additional scattering from long cosmic strings along its route. Second manner to deduce the curvature is by measuring correlations from sets of 4 points in the sky. The correlations should not change if TGD is correct. I do do not understand enough these correlations to tell whether the presence of cosmic strings and flux tubes affect the correlations or not.

The conceptual and technical challenge is to understand how two treat cosmic strings in the QFT-GRT limit of TGD based fractal cosmology.

1. For space-time surfaces with 4-D M^4 projection the GRT space-time is obtained as 4-D piece of M^4 with gauge potentials and the deviation of metric from flat M^4 metric as a sum of those for space-time sheets. One actually obtains a length scale hierarchy of space-times assignable to causal diamonds (CDs) and standard cosmology should correspond to the limit of CD size, which is about the size of the recent cosmology. CMB data indeed suggest length scale dependence of CMB parameters.

2. At every step in hierarchy 3-space is finite corresponding to the radius of CD at give value of Minkowski time. The actual 3-surfaces are always closed and can be though of as pairs of 3-surfaces with boundary at boundary of CD glued together along their boundaries. Covering of flat 3-space would be in question. Could this somehow relate to why closed Universe seems to work in some respects?

   The hierarchy brings in new elements such as hierarchy of cosmological constants with a concrete interpretation discussed elsewhere.

3. But what should one do with the cosmic strings and flux tubes? The addition of them as singular string world sheets in space-time carrying concentrated a string world sheet is one possibility which comes into mind. GRT based cosmology relies on pointlike objects and infinitely long cosmic strings are not pointlike objects in any scale. A more plausible approach would be in terms of tensor nets with cosmic strings and flux tubes defining the connections between the nodes of the net. The identification of dark matter as $h_{eff} = n \times h_0$ phases of ordinary matter would make possible quantum coherence in arbitrarily long length scales. Fractal tensor net would be genuinely quantal object in all scales, and provide very different view about the role of quantum dynamics in cosmology and astrophysics.

13.2 The problem of two Hubble constants

I received a link to a popular article relating to the two values of Hubble constant (see `http://tinyurl.com/yxgvsaam`). The popular article states that the expansion is 9 per cent faster than expected. This problem is old and earlier and has been seen discrepancy: measurement suggest two different values of Hubble constant. The article suggests that the bigger value is now accepted as the correct value. Hype warning is in order. The refusal to accept the possibility of two different values might mean only the continuation of the long lasting fruitless debate. It is better two try to explain why two different values are obtained.

I have considered the problem of two value of cosmological constant already earlier in the framework provided by many-sheeted space-time [K20]. In the sequel the puzzle of two Hubble constants is discussed applying the recent view about cosmological constant. What is new that twistor lift of TGD [L10] predicts that cosmological constant is length scale dependent and that cosmological expansion consists of jerks involving accelerated periods followed by a phase transition changing reducing cosmological constant by a negative power of two and and inducing the transformation of the magnetic energy of monopole flux tubes to ordinary matter.

Monopole flux tubes have become a central element of TGD inspired cosmology and astrophysics and the natural question is whether length scale dependent cosmological constant could solve the Hubble discrepancy? It seems that the higher value of cosmological constant corresponds to a smaller scale for observations: this could explain the discrepancy. The model requires a more detailed consideration of what it it is to be a standard candle. In many-sheeted space-time of TGD also the environment of the standard candle identified as monopole flux tube matters.

For distant standard candles the environment defined by the flux tube is younger than for nearby ones. The thickening associated with the aging of the flux tubes involving the decay of magnetic energy to ordinary matter. The reduction of magnetic energy density in turn increases the value of the metric component $\sqrt{g_{aa}}$ in the natural space-time coordinates provided by the Robertson-Walker coordinates of the light-cone (a corresponds to the proper time coordinate of the light-cone). This can give rise to the increase of the Hubble constant $H = 1/\sqrt{g_{aa}}a$ explaining why the nearby flux tubes correspond to a larger value Hubble constant. Therefore monopole magnetic flux tubes could explain also the Hubble constant discrepancy.

The many-sheeted space-time suggests a possible solution to the Hubble constant discrepancy.

1. The first TGD based explanation coming into mind is based on many-sheeted space-time that I proposed decades ago. The value of Hubble constant depends on the metric of the space-time sheet the the p-adic size scale assignable to the space-time sheet. Could the measured values of Hubble constant which differ by 9 per cent correspond to different space-time sheets having slightly different Hubble constants. p-Adic length scales come as half octaves and different p-adic lengths scales would suggest a larger difference. For instance, there is evidence that the gamma rays and neutrinos from supernova SN1987A propagated with several velocities [K32] and the explanation could be the same.

2. Could length scale dependent cosmological constant assignable to the space-time surfaces solve the problem? Could it lead to length scale dependent Hubble constant H explaining the 9 per cent discrepancy as reflecting different values of H at long and short distances or equivalently at different values of cosmological time?

In the sequel the latter option - actually a more precise formulation of the first one - is considered. An essential element of the model is the notion of length scale dependent cosmological constant predicted by the twistor lift of TGD and the phase transitions reducing the value of Λ followed by the thickening of the flux tubes induced by the decay of the magnetic energy to ordinary matter. This would lead to the increase of the Hubble constant associated with the flux tube.

13.2.1 The notion of length scale dependent cosmological constant

TGD predicts that cosmological constant Λ characterizing space-time sheets is length scale dependent and depends on p-adic length scale. Furthermore, expansion would be fractal and occur in jerks. This is the picture that twistor lift of TGD leads to [L10].

Quite generally, cosmological constant defines itself a length scale $R = 1/\Lambda^{1/2}$. $r = (8\pi)^{1/4}\sqrt{Rl_P}$ - essentially the geometric mean of cosmological and Planck length - defines second much shorter length scale r. The density of dark energy assignable to flux tubes in TGD framework is given as $\rho = 1/r^4$.

In TGD framework these scales corresponds two p-adic length scales coming as half octaves. This predicts a discrete spectrum for the length scale dependent cosmological constant Λ [L10]. For instance, one can assign to ..., galaxies, stars, planets, etc... a value of cosmological constant. This makes sense in many-sheeted space-time but not in standard cosmology.

Cosmic expansion is replaced with a sequence of fast jerks reducing the value of cosmological constant by some power of 2 so that the size of the system increases correspondingly. The jerk involves a phase transition reducing Λ by some negative power of 2 inducing an accelerating period during which flux tube thickness increases and magnetic energy transforms to ordinary matter. Thickening however increases volume energy so that the expansion eventually halts. Also the opposite process could occur and could correspond to a "big" state function reduction (BSFR) in which the arrow of time changes.

An interesting question is whether the formation of neutron stars and super-novas could involve BSFR so that these collapse phenomena would be kind of local Big Bangs but in opposite time direction. One can also ask whether blackhole evaporation could have as TGD analog BSFR meaning return to original time direction by a local Big Bang. TGD analogs of blackholes are discussed in [L20].

Consider now some representative examples to see whether this picture can be connected to empirical reality.

1. Cosmological constant in the length scale of recent cosmology corresponds to $R \sim 10^{26}$ m (see `http://tinyurl.com/k4bwlzu`). The corresponding shorter scale $r = (8\pi)^{1/4}\sqrt{Rl_P}$ is identified essentially as the geometric mean of R and Planck length l_P and equals to $r \sim 4 \times 10^{-4}$ m: the size scale of large neuron. This is very probably not an accident: this scale would correspond to the thickness of monopole flux tubes.

2. If the large scale R is solar radius about 7×10^8 m, the short scale $r\simeq 10^{12}$ m is about electron Compton length, which corresponds to p-adic length scale $L(127)$ assignable to Mersenne prime $M_{127}=2^{127}-1$. This is also the size of dark proton explaining dark fusion deduced from Holmlid's findings [L13, L15]: this requires $h_{eff}\sim 2^{12}$!

   Remark: Dark proton sequences could be neutralized by a sequence of ordinary electrons locally. This could give rise to analogs of atoms with electrons being very densely packed along the flux tube.

   The prediction of the TGD based model explaining the 10 year old puzzle related to the fact that nuclear abundances in solar interior are larger than outside [L24] (see `http://tinyurl.com/y38m54ud`) assumes that nuclear reactions in Sun occur through intermediate states which are dark nuclei. Hot fusion in the Sun would thus involve the same mechanism as "cold fusion". The view about cosmological constant and TGD view about nuclear fusion lead to the same prediction.

3. If the short scale is p-adic length $L(113)$ assignable to Gaussian Mersenne $M_{G,113}=(1+i)^{113}-1$ defining nuclear size scale of $r\sim 10^{-14}$ m, one has $R\sim 10$ km, the radius of a typical neutron star (see `http://tinyurl.com/y5ukv2wt`) having a typical mass of 1.4 solar masses.

   A possible interpretation is as a minimum length of a flux tube containing sequence of nucleons or nuclei and giving rise to a tangle. Neutron would take volume of about nuclear size - size of the magnetic body of neutron? Could supernova explosions be regarded as phase transitions scaling the stellar Λ by a power of 2 by making it larger and reducing dramatically the radius of the star?

4. Short scale $r\sim 10^{-15}$ m corresponding to proton Compton length gives R about 100 m. Could this scale correspond to quark star (see `http://tinyurl.com/y3n78tjs`)? The known candidates for quark stars are smaller than neutron stars but have considerably larger radius measured in few kilometers. Weak length scale would give large radius of about 1 cm. The thickness of flux tube would be electroweak length scale.

13.2.2 Accelerated expansion in standard cosmology

To be contact with basic numbers consider first the accelerated cosmic expansion in standard model.

1. Hubble constant is defined as the parameter

$$H^2=(\frac{\dot{a}}{a})^2 \quad . \tag{13.1}$$

   Here the shorthand $\dot{a}I=da/dt$ has been used. TGD inspired cosmology one can use Robertson-Walker coordinates as natural space-time coordinates without assuming the symmetries of Robertson-Walker cosmologies, and a corresponds to the light-cone proper time. Time coordinate t corresponds to proper time coordinate of space-time surface and one has $dt^2=g_{aa}da^2$ so that one has $dt/da=\sqrt{g_{aa}}$. Therefore one can also write

$$H^2=\frac{1}{g_{aa}a^2} \quad . \tag{13.2}$$

   In the simplified model redshift z relates to the scale factor via the formula

$$\frac{a(t)}{a(t_{now})}=\frac{f_{obs}}{f_{emit}}=\frac{1}{1+z} \quad . \tag{13.3}$$

   Here t corresponds to the value of cosmic proper time when the radiation was emitted. Accelerated expansion means that the objects are farther than they would be if the Hubble constant had had its present value all the time.

2. Friedmann equation states that the square H^2 of Hubble constant (see http://tinyurl.com/o8l9oro) can be written as a sum of 4 contributions.

$$H^2 = \frac{8\pi G}{3}(\rho_m + \rho_r) - \frac{k}{a^2} + \frac{\Lambda}{3}) \ . \tag{13.4}$$

The first term is proportional to mass density ρ_m of matter and second term to the mass density ρ_r of radiation. Second ter is curvature contribution depending on the parameter $k = -1, 0, 1$ characterizing the 3-curvature of 3-space. For hyperbolic cosmology expanding forever one has k=-1. Curvature radius a corresponds in TGD to the light-cone proper time coordinate. The third term corresponds to dark energy and cosmological constant. It is positive since the expansion is accelerated. This observation was fatal for superstring theory.

3. One can write the expression of Hubble constant also in the form (see http://tinyurl.com/ycv2t7w6)

$$H^2 = H_0^2(\Omega_k a^{-2} + \Omega_m a^{-3} + \Omega_r a^{-4} + \Omega_{DE} a^{-3(1+w)}) \ . \tag{13.5}$$

H_0 corresponds to Hubble constant for critical mass density and various terms correspond to curvature, matter, radiation and vacuum energy. Experimentally the parameter w characterizes the dark energy density. For $w = -1$ one has cosmological constant, which in TGD would correspond to 3-surfaces very large in all dimensions. For $w = -1/3$ one has $1/a^2$ behavior and ideal cosmic strings and acceleration parameter vanishes in this case. The real situation in TGD is between these two since cosmic strings are thickened to flux tubes.

4. The acceleration equation reads is counterpart of Newton's equation

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3P) \ . \tag{13.6}$$

The pressure term is negative for the accelerated expansion and it is difficult to assign it to ordinary particles. In TGD framework the tension of cosmic strings thickened to flux tube and containing magnetic and volume contribution to energy momentum tensor would give rise to effective negative pressured term.

5. If one assumes that pressure relates to the density of energy as

$$P = w\rho \ . \tag{13.7}$$

one obtains the parameterization given for Hubble constant in terms of w. I am not sure whether this is the most general parameterization of pressure. For $w = -1$ one has Λ_{CDM} model with constant density of dark energy. This corresponds in TGD to 3-surfaces which are large in all directions. $w = -1/3$ corresponds to cosmic strings and cosmic strings thickened to flux tubes correspond to $-1 < w < -1/3$ giving rise to accelerated expansion during the period when cosmological constant associated with volume actions remains constant. The period ends when a phase transition reducing its value by a negative power of 2 takes place. This gives to jerk-wise cosmological expansion, which occurs in all scales.

6. The technical definition for the accelerate expansion is by the following equation

$$\frac{dH}{dt} = -H^2(1 + q) \ . \tag{13.8}$$

q is known as deceleration parameter. For $q > -1$ H increases with time. Observations suggest $q = -.55$ so that one has accelerating expansion with $d^a/dt^2 > 0$ but with decreasing H.

13.2.3 Accelerated expansion in TGD framework

Consider first the TGD based model for the accelerated expansion.

1. TGD predicts length scale dependent cosmological constant at the level of space-time as the coefficient of the volume term of the action obtained by dimensional reduction from the Kähler action for twistor lift.

   The first thing to notice is that this cosmological constant need not directly relate to the cosmological constant of QFT limit expect when the space-time surfaces have large dimensions in all directions. For string like objects only one dimension is large and in this case the volume energy is proportional to the length rather than volume. In the idealization that string like objects are infinitely thin the energy of string phase is proportional to $1/a^2$ as function of cosmic time rather than constant as for cosmological constant in GRT. This formula expresses the fact that the amount of string inside comoving volume is proportional to a.

2. There is however a sequence of phases transition reducing the cosmological constant to which volume energy of space-time surface is proportional to. The phase transitions induce accelerated expansion (due to accelerated thickening of monopole flux tubes) as their magnetic energy transforms to ordinary matter [L10] (see `http://tinyurl.com/y2h9wr3`). Eventually the increase of volume energy stops this accelerated expansion. One can argue that (or at least ask whether) this fastens the expansion rate temporarily. Inflation and the recent accelerated expansion would be examples of this kind jerks replacing smooth cosmological expansion in TGD Universe. These jerks occur in all scale: even in scale of Earth [L18] (see `http://tinyurl.com/yc4rgkco`).

3. Since cosmological constant and thus string tension behaves like $1/a^2$ in average sense, the energy density of strings decreases as $1/a^3$ in average sense and strings correspond to comoving matter in this sense. Hence the occurrence of the phase transitions reducing the value of Λ allow avoid the big rip predicted by the standard model.

4. During a period with given value of space-time cosmological constant the situation is between string dominated cosmology and that involving cosmological constant since flux tubes are between cosmic strings and very thick cosmic strings corresponding to cosmological constant. Therefore one expects that the parameter w characterizing acceleration expansion is between the values $w = -1/3$ corresponding to cosmology dominated by ideal strings with no acceleration and $w = -1$ corresponding to cosmological constant.

   It is not quite clear to me that the decay of magnetic energy of flux tubes to ordinary matter is responsible for accelerated expansion although by the conservation of the monopole flux it associated with the thickening of strings.

Remark: In zero energy ontology (ZEO) the TGD counterpart of "big" (ordinary) state function reduction (BSFR) changes the arrow of time whereas "small" state function reductions (SSFRs) serving as TGD counterparts of weak measurements preserve the arrow. The strange findings of Minev *et al* support the change of the arrow of time in BSFRs in atomic systems [L21]. The causal anomalies associated with earthquakes and volcanic eruptions suggest that even these events can correspond to BSFRs in TGD Universe [L23].

Could the formation of TGD counterparts of blackhole be BSFR and correspond to a transformation of dark energy of the thickening cosmic string to ordinary matter but in reverse direction of time [L20]? Could the formation of galaxies and perhaps even stars and planets have interpretation as a formation of white-hole - blackhole in opposite time direction involving a transformations of the dark energy of cosmic string to ordinary matter [L24]?

Could BSFRs take place even in cosmological scales [L17]? Could the phase transitions reducing the value of length scale dependent Λ be BSFRs? Thermodynamics favours the decrease of Λ, which suggests that the arrow of time does not change and SSFR is in question. If Λ increased, the arrow time would change and the process could be actually BSFR producing a cosmology with opposite arrow of time.

13.2.4 Could one understand the two values of Hubble constant in TGD Universe?

Flux tubes are the new element brought by TGD to cosmology, and it would not be surprising if they were essential for the understanding of the Hubble constant discrepancy. A valuable hint comes from the observation that different values of Hubble constant seem to correspond to measurements carried out in different scales: this is due to different methods to determine H from redshift - and distance data.

1. The value of Λ assignable to space-time sheets is expected to come as negative powers of 2. It is not plausible that this could explain the two different values of H. Dark energy density is estimated to be 68 per cent of the total so that this term is the largest and the reduction of this term in the formula for H^2 by factor of say 1/4 is expected to have much larger effect on H than 9 per cent. The value of Λ for space-time surface must be same for the measurements giving different value of H as already noticed.

2. From the formula $H^2 = 1/g_{aa}a^2$ one finds that the value of g_{aa} at recent time as predicted from that in distant past is larger than predicted. The positive value of $\ddot{a}$ implies that $\dot{a} = 1/\sqrt{g_{aa}}$ has increased and objects are at larger distance than they would be in absence of accelerated expansion. The idealization $H = constant$ making sense at short distances to the source corresponds to $g_{aa} \propto 1/a$ predicting $a \propto exp(t)$. The value of g_{aa} assignable to the distant objects seems to be larger than $g_{aa} \propto 1/a$ would predict. g_{aa} decreases faster than constant H predicts.

3. What does standard candle property mean in TGD framework? Standard candles as astrophysical objects should be identical, in particular they should have same age. In many-sheeted space-time there are however additional factors involved.

   Option I: Standard candle (or rather the emitters of standard candle) has environment. Let us assume that it corresponds to a flux tube. At the moment of emission this flux tube is older for nearby objects than for distant ones.

   Option II: Radiation propagates along flux tubes connecting observer and source region. Suppose that one can model it as massless extremal associated with a flux tube. For nearby sources these flux are younger than for distant sources. If these flux tubes are responsible for the effect, it is opposite to that for Option I.

4. With standard arrow of time for flux tubes, the flux tubes should thicken by the transformation of magnetic energy to ordinary matter. The loss of magnetic energy should decrease g_{aa} faster than $1/a$. The longer the flux tube, the larger the decrease of g_{aa} would be since the decrease of the energy of the flux tube increases g_{aa}. H would be smaller for older flux tubes.

5. Scale dependence means that nearby standard candles correspond to a larger value of H. For Option I, H is indeed larger for nearby sources than distant ones. For Option II H is smaller for nearby sources than distant ones, which is obviously wrong. Option II can work only if the arrow of time is non-standard for the flux tubes along which radiation propagates.

To sum up, in TGD Universe also flux tubes serving as links of the cosmic network are essential besides source and receiver and the length and thus age of the flux tube could be essential for the explanation of Hubble constant discrepancy.

13.2.5 A solution to the Hubble constant discrepancy?

This comment was inspired about year after writing the above proposal by an interesting popular article about a possible explanation of Hubble constant discrepancy (`http://tinyurl.com/yd783ow6`). The article told about a proposal of Lucas Lombriser discussed in the article *Consistency of the local Hubble constant with the cosmic microwave background* [E36] (`http://tinyurl.com/ycd4aenh`) for an explanation of this discrepancy. The proposal is that the local region around our galaxy having size of order few hundred Mly - this is the scale of the large voids forming a honeycomb like structure containing galaxies at their boundaries - has average density of the matter 1/2 of that elsewhere.

Consider first the discrepancy. The determination of Hubble constant characterizing the expansion rate of the Universe can be deduced from cosmic microwave background (CMB). This corresponds to long length scales and gives value $H_{cosmo} = 67.4$ km/s/Mpc. Hubble constant can be also deduced from local measurements using so called standard candles in the scales of large voids. This gives Hubble constant $H_{loc} = 75.7$ km/s/Mpc, which is by about 10 percent higher.

The argument of the article is rather simple.

1. It is a well-known fact that Universe decomposes into giant voids with size scale of 10^8 light years. The postulated local region would have this size and mass density would be reduced by factor 1/2.

   Suppose that standard candles used to determine Hubble constant belong to this void so that density is lower than average density. This would mean that the Hubble constant H_{loc} for local measurements of Hubble constant using standar candles would be higher than H_{cosmo} from measurements of CMB.

2. Consider the geometry side of Einstein's equations. Hubble constant squared is given by

$$H^2 = (\frac{dlog(a)}{dt})^2 = \frac{1}{g_{aa} \times a^2} \quad .$$

   Here one has $dt^2 = g_{aa} da^2$. t is proper time for a comoving observer and a is the scale factor in the spatial part of Robertson-Walker metric. The reduction of H^2 is caused by the increase of g_{aa} as the density decreases. At the limit of empty cosmology (future light-one) $g_{aa} = 1$. Hubble constant is largest at this limit for given a, which in TGD framework corresponds to light-cone proper time coordinate.

3. The matter side of Einstein's equations gives

$$H^2 = \frac{8\pi G}{3}\rho_m + \frac{\Lambda}{3} .$$

   The first contribution corresponds to matter and second dark energy, which dominates.

4. It turns out that be reducing ρ_m by factor 1/2, the value of H_{loc} is reduced by about 10 percent so that H_{loc} agrees with H_{cosmo}.

Could one understand the finding in TGD framework? It seems that Hubble constant depends on scale. This would be natural in TGD Universe since TGD predicts p-adic hierarchy of scales coming as half octaves. One can say that many-sheeted space-time gives rise to fractal cosmology or Russian doll cosmology.

Cosmological parameters would depend on scale. For instance, cosmological constant would come naturally as octave of basic values and approach to zero in long length scales. Usually it is constant and this leads to the well-known problem since its value would be huge by estimates in very short length scales. Also its sign comes out wrong in super string theories whereas twistor lift of TGD predicts its sign correctly.

I have already earlier tried to understand the discrepancy in TGD framework in terms of many-sheeted space-time suggesting that Hubble constant depends on space-time sheet - first attempts were first applications of TGD inspired cosmology for decades ago - but have not found a really satisfactory model. The new finding involving factor 1/2 characteristic for p-adic length scale hierarchy however raises hopes about progress at the level of details.

1. TGD predicts fractal cosmology as a kind of Russian doll cosmology in which the value of Hubble constant depends on the size scale of space-time sheet. p-Adic length scale hypothesis states that the scale comes in octaves. One could therefore argue that the reduction of mass density by factor 1/2 in the local void is natural. One can however find objections.

2. The mass density scales as $1/a^3$ and one could argue that the scaling could be like $2^{-3/2}$ if p-adic length scale increas by factor 2. Here one can argue that in TGD framework matter is at magnetic flux tubes and the density therefore scales down by factor 1/2 meaning reduction of string tension by this factor.

3. One can argue that also the cosmological term in mass density would naturally scale down by 1/2 as p-adic length scales is scaled up by 2. If this happened the Hubble constant would be reduced by factor $1/2^{1/2}$ roughly since dark energy dominates. This does not happen.

   Should one assign dark energy parameter Ω to a space-time sheet having scale considerably larger than that those carrying the galactic matter? Should one regarded large void as a local sub-cosmology topologically condensed on much larger cosmology characterized by Ω? But why not use Ω associated with the sub-cosmology? Could it be that the Ω of sub-cosmology is included in ρ_m?

Could the following explanation work? TGD predicts two kinds of magnetic flux tubes: monopole flux tubes, which ordinary cosmologies and Maxwellian electrodynamics do not allow and ordinary flux tubes representing counterparts of Maxwellian magnetic fields. Monopole flux tubes need not currents to generate their magnetic fields and this solves several mysteries related to magnetism: for instance, one can understand why Earth's magnetic field has not decayed long time ago by the dissipation of the currents creating it. Also the existences of magnetic fields in cosmic scales impossible in standard cosmology finds explanations.

1. First kind of flux tubes carry only volume energy since the induced Kähler form vanishes for them and Kähler action is vanishing. There are however induced electroweak gauge fields present at them. I have tentatively identified the flux tubes mediating gravitational interaction with these as these flux tubes.

   Could Ω correspond to cosmological constant assignable to gravitational flux tubes involving only volume energy and be same also in the local void? This because they mediate very long range and non-screened gravitational interaction and correspond to very long length scales.

2. Second kind of flux tubes carry non-vanishing monopole flux associated with the Kähler form and the energy density is sum of volume term and Kähler term. These flux tubes would be carriers of dark energy generating gravitational field orthogonal to the flux tubes explaining the flat velocity spectrum for distant stars around galaxies. These flux tubes be present in all scales would play central role in TGD based model of galaxies, stars, planets, quantum biology, molecular and atomic physics, nuclear physics and hadron physics.

   These flux tubes suffer phase transitions increasing their thickness by factor 2 and reducing the energy density by factor 1/2. This decreases gradually the value of energy density associated with them.

   Could the density ρ_m of matter correspond to the density of matter containing contributions from monopole flux tubes and their decay products: ρ_m would therefore contain also the contribution from both magnetic and volume energy of flux tubes. Could it have been scaled down in a phase transition reducing locally the value of string tension for these flux tubes. Our local void would be one step further in the cosmic evolution by reductions and have experience one more expansions of flux tube thickness by half octave than matter elsewhere.

REFERENCES

Mathematics

[A1] Crystal structure. Available at: `https://en.wikipedia.org/wiki/Crystal_structure`.

[A2] Gieseking manifold. Available at: `https://en.wikipedia.org/wiki/Gieseking_manifold`.

[A3] Hyperbolic manifold. Available at: `https://en.wikipedia.org/wiki/hyperbolic_manifold`.

[A4] Icosahedral graph. Wolfram MathWorld. Available at: https://mathworld.wolfram.com/IcosahedralGraph.html.

[A5] Infinite skew polyhedron. Available at: https://en.wikipedia.org/wiki/Infinite_skew_polyhedron.

[A6] Kleinian group. Available at: https://en.wikipedia.org/wiki/Kleinian_group.

[A7] List of regular polytopes. Available at: https://en.wikipedia.org/wiki/List_of_regular_polytopes.

[A8] Modular group. Available at: https://en.wikipedia.org/wiki/Modular_group.

[A9] Penrose tilings. Available at: https://en.wikipedia.org/wiki/Penrose_tilings.

[A10] Point group. Available at: https://en.wikipedia.org/wiki/Point_group.

[A11] Schläfli symbol. Available at: https://en.wikipedia.org/wiki/Schl\unhbox\voidb@x\bgroup\let\unhbox\voidb@x\setbox\@tempboxa\hbox{a\global\mathchardef\accent@spacefactor\spacefactor}\let\begingroup\endgroup\relax\let\ignorespaces\relax\accent127a\egroup\spacefactor\accent@spacefactorfli_symbol.

[A12] Seifert–Weber space. Available at: https://en.wikipedia.org/wiki/Seifert\OT1\textendashWeber_space.

[A13] Space group. Available at: https://en.wikipedia.org/wiki/Space_group.

[A14] Surface bundle over the circle. Available at: https://en.wikipedia.org/wiki/Surface_bundle_over_thecircle.

[A15] Thurston's theorem. Available at: https://en.wikipedia.org/wiki/Thurston's_geometrization_conjecture.

[A16] Thurston's theorem. Available at: https://en.wikipedia.org/wiki/Thurston's_theorem.

[A17] Weeks manifold. Available at: https://en.wikipedia.org/wiki/Weeks_manifold.

[A18] Why are there 1024 Hamiltonian cycles on an icosahedron? Available at: https://tinyurl.com/pmghcwd.

[A19] Brujin de NG. Algebraic theory of Penrose's nonperiodic tilings of the plane. I, II. *Nederl Akad Wetensch Indag Math*, 43(1):39,52,53–66, 1981.

[A20] Effinger-Dean L. Empire problem for Penrose tilings, 2006. Available at: https://homes.cs.washington.edu/~effinger/files/empire.pdf.

[A21] Lapidus ML. *In Search of the Riemann Zeros: Strings, Fractal Membrans and Noncommutative Spacetimes*. AMS, 2008.

Theoretical Physics

[B1] Baryogenesis. Available at: https://en.wikipedia.org/wiki/Baryogenesis.

[B2] Chiral anomaly. Available at: https://en.wikipedia.org/wiki/Chiral_anomaly.

[B3] Instanton. Available at: https://en.wikipedia.org/wiki/Instanton.

[B4] Sphaleron. Available at: https://en.wikipedia.org/wiki/Sphaleron.

[B5] Summary about spinors in different dimensions. Available at: https://www.fis.puc.cl/~jalfaro/supergravity/III-Supergravity48-77.pdf.

[B6] Ringwald A. Instantons/Sphalerons: Searching for New Physics with the Standard Model. Available at: https://www.desy.de/~ringwald/talks/fridgerfest.pdf.

[B7] Riotto A. Theories of baryogenesis. Available at: https://arxiv.org/abs/hep-ph/9807454.

[B8] Rafelski J Ericson T. The tale of the Hagedorn temperature. *Cern Courier*, 43(7), 2002. Available at: https://www.cerncourier.com/main/toc/43/7.

[B9] Davidson S et al. Leptogenesis. Available at: https://arxiv.org/pdf/0802.2962v3.pdf.

[B10] D'onofrio M et al. The sphaleron rate at the electroweak crossover with 125 GeV Higgs mass. Available at: https://arxiv.org/pdf/1212.3206v1.pdf.

[B11] Tegmark M et al. How accurately can 21 cm tomography constrain cosmology?, 2008.Available at:https://arxiv.org/abs/0802.1710.

[B12] Kenia HS. Introduction to sphalerons. Available at: https://hep.uchicago.edu/~mattlow/qft_papers/Kedia_Sphalerons.pdf.

[B13] Freedman MH. P/NP, and the quantum field computer. *Proc Natl Acad Sci USA*, 95(1), 1998.

[B14] Arkani-Hamed N and Maldacena J. Cosmological Collider Physics, 2015.Available at:https://arxiv.org/pdf/1503.08043v1.

[B15] Broniowski W. Two Hagedorn temperatures, 2002. Available at: https://arxiv.org/abs/hep-ph/0006020.

Particle and Nuclear Physics

[C1] CMS observes a potentially new and interesting effect. Available at: https://user.web.cern.ch/user/news/2010/100921.html.

[C2] LHC probably sees new shocking physics, 2010. Available at: https://motls.blogspot.com/2010/09/lhc-probably-sees-new-shocking-physics.html.

[C3] Alice Collaboration. Charged-particle multiplicity density at mid-rapidity in central Pb-Pb collisions at $\sqrt{s_{NN}}$= 2. 76 TeV, 2010. Available at: https://arxiv.org/abs/1011.3916.

[C4] CMS Collaboration. Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC, 2010. Available at: https://cms.web.cern.ch/cms/News/2010/QCD-10-002/QCD-10-002.pdf.

[C5] Samuel E. Ghost in the Atom. *New Scientist*, (2366):30, 2002.

[C6] Reich ES. Black hole like phenomenon created by collider. *New Scientist*, 19(2491).

[C7] Back BB et al. *Nucl Phys A*, 698:416, 2002.

[C8] Back BB et al. *Phys Rev Lett* .. Available at: https://arxiv.org/abs/hep-ex/0208004, 89(22), 2002.

[C9] Davies DT et al. Precise Charm to Strange Mass Ratio and Light Quark Masses from Full Lattice QCD. *Phys Rev*, 104, 2010. Available at: https://prl.aps.org/abstract/PRL/v104/i13/e132003.

[C10] Derrick M et al. *Phys Lett B*, 315:481, 1993.

[C11] Nastase H. The RHIC fireball as a dual black hole, 2005. Available at: https://arxiv.org/abs/hep-th/0501068.

[C12] McLerran L Ludham T. What Have We Learned From the Relativistic Heavy Ion Collider? *Phys Today* . Available at: https://www.physicstoday.org/vol-56/iss-10/p48.html, 2003.

Condensed Matter Physics

[D1] Viscosity. Available at: https://en.wikipedia.org/wiki/Viscosity.

[D2] Cao C et al. Universal Quantum Viscosity in a Unitary Fermi Gas, 2010. Available at: https://www.sciencemag.org/content/early/2010/12/08/science.1195219.

[D3] Mills R et al. Spectroscopic and NMR identification of novel hybrid ions in fractional quantum energy states formed by an exothermic reaction of atomic hydrogen with certain catalysts, 2003. Available at: https://www.blacklightpower.com/techpapers.html.

[D4] Widom M. Discussion of phasons in quasicrystals and their dynamics. *Philosophical Magazine*, 88(13-15):2339–2350, 2008. Available at: https://euler.phys.cmu.edu/widom/pubs/PDF/PhilMag88_2008_p2339.pdf.

Cosmology and Astro-Physics

[E1] Cosmic inflation. Available at: https://en.wikipedia.org/wiki/Cosmic_inflation.

[E2] Cosmic Microwave Background. Available at: https://en.wikipedia.org/wiki/Microwave_background.

[E3] Λ-CDM model. Available at: https://en.wikipedia.org/wiki/Lambda-CDM_model.

[E4] Quintessence. Available at: https://en.wikipedia.org/wiki/Quintessence.

[E5] Scalar-vector-tensor decomposition. Available at: https://en.wikipedia.org/wiki/Scalar-vector-tensor_decomposition.

[E6] Voids. Available at: https://en.wikipedia.org/wiki/Void_(astronomy).

[E7] Riess AG. *PASP*, 112, 2000.

[E8] Schaefer B. The hubble diagram to z = 6.3 with swift gamma ray bursts, 2006. Available at: https://www.phys.lsu.edu/GRBHD/.

[E9] Kohri K Chiva T. Quintessence Cosmology and Varying α, 2001. Available at: https://arxiv.org/abs/hep-ph/0111086.

[E10] Hogan CJ. Measurement of Quantum Fluctuations in Geometry, 2008. Available at: https://arxiv.org/abs/gr-gc/0712.3419.

[E11] Shiga D. Mysterious source of cosmic rays detected, 2006. Available at: https://tinyurl.com/pou4b83.

[E12] Nottale L Da Rocha D. Gravitational Structure Formation in Scale Relativity, 2003. Available at: https://arxiv.org/abs/astro-ph/0310036.

[E13] Costa Oliveira de A et al. The significance of the largest scale CMB fluctuations in WMAP, 2003. Available at: https://arxiv.org/abs/asto-ph/0307282.

[E14] Silk J Di Valentino E, Melchiorri A. Planck evidence for a closed Universe and a possible crisis for cosmology. *Nature Astronomy*, 2019. Available at:https://www.nature.com/articles/s41550-019-0906-9.

[E15] Ackerman et al. A Cocoon of Freshly Accelerated Cosmic Rays Detected by Fermi in the Cygnus Superbubble. *Science*, 25:2203–2207, 2011. Available at: `https://www.sciencemag.org/content/334/6059/1103.abstract`.

[E16] Aqilar M et al. Properties of Cosmic Deuterons Measured by the Alpha Magnetic Spectrometer Antihelium nuclei. *Phys Rev Lett*, 132(261001), 2024. Available at: `https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.132.261001`.

[E17] Bennett CL et al. *Astrophys. J*, 148, 2003. Available at: `https://arxiv.org/abs/astro-ph/0302207`.

[E18] Chand H et al. *Astron Astrophys*, 417, 2004.

[E19] Copi CJ et al. Multiple Vectors- a new representation of the CBM sky and evidence for statistical anisotropy or non-Gaussianity at $2 \leq l \leq 8$, 2004.Available at: `https://arxiv.org/abs/astro-ph/0310511`.

[E20] Copi CJ et al. The Uncorrelated Universe: Statistical Anisotropy and the Vanishing Angular Correlation Function in WMAP YEars 1-3, 2004.Available at: `https://arxiv.org/abs/astro-ph/0605135`.

[E21] Eriksen HK et al. Asymmetries in the CMB anisotropy field, 2003.Available at: `https://arxiv.org/abs/astro-ph/0307507`.

[E22] Freedman WL et al. *Nature*, 371, 1994.

[E23] Freeman PE et al. Examining the Effect of the Map-making Algorithm on Observed Power Asymmetry in WMAP Data. *Astrophys J*, 638, 2006. Available at: `https://arxiv.org/abs/astro-ph/0510406`.

[E24] Hajian A et al. On the apparent lack of power in the CMB anisotropy at large scales, 2003. Available at: `https://arxiv.org/abs/astro-ph/0702723`.

[E25] Hogan CJ et al. Search for Space-Time Correlations from the Planck Scale with the Fermilab Holometer, 2015. Available at: `https://arxiv.org/abs/1512.01216`.

[E26] Perlmutter S et al. *Ap J*, 483, 1997.

[E27] Pierce JM et al. *Nature*, 371, 1994.

[E28] Riess AG et al. Type Ia Supernova Discoveries at $z > 1$ from the Hubble Space Telescope: Evidence for Past Deceleration and Constraints on Dark Energy Evolution, 2004. Available at: `https://arxiv.org/abs/astro-ph/0402512`.

[E29] Riess AG et al. Determination of the local value of the hubble constant, 2016.Available at:`https://arxiv.org/pdf/1604.01424.pdf`.

[E30] Webb JK et al. Further Evidence for Cosmological Evolution of the Fine Structure Constant, 2001. Available at: `https://arxiv.org/abs/astro-ph/0012539`.

[E31] Webb JK et al. Further Evidence for Cosmological Evolution of the Fine Structure Constant. *Phys Rev*, 87(9), 2001.Available at: `arxiv.org/abs/astro-ph/0012539`.

[E32] Webb JK et al. Four direct measurements of the fine-structure constant 13 billion years ago. *Science Advances*, 6(17), 2020. Available at:`https://advances.sciencemag.org/content/6/17/eaay9672`.

[E33] Sato H Fang LZ. Is the Periodicity in the Distribution of Quasar Red Shifts an Evidence of Multiple Connectedness of the Universe? *Gen Rel & Grav*, (11), 1985.

[E34] Bekenstein J. *Phys Rev D*, 25, 1982.

[E35] Grossmann L. Cosmic ray factory observed in stellar superbubble, 2011. Available at: `https://tinyurl.com/o5pgkb4`.

[E36] Lombriser L. Consistency of the local Hubble constant with the cosmic microwave background. *Phys. Lett. B*, 803(135303), 2020. Available at: https://doi.org/10.1016/j.physletb.2020.135303.

[E37] Zyga L. Discovery that quasars don't show time dilation mystifies astronomers, 2010. Available at: https://www.physorg.com/news190027752.html.

[E38] Chown M. Our world may be a giant hologram. *New Scientist*, 2009. Available at: https://tinyurl.com/8ah9az., 2009.

[E39] Hawkins MR. On time dilation in quasar light curves. *Month Not R Astron Soc*, 405(3):1940–1946, 2010. Available at: https://www3.interscience.wiley.com/journal/123345710/abstract.

[E40] Mead LR Ringermacher HI. Observation of Discrete Oscillations in a Model-independent Plot of Cosmological Scale Factor vs. Lookback Time and a Scalar Field Model, 2015. Available at: https://arxiv.org/abs/1502.06140.

[E41] von Doetinchem P et al. Cosmic-ray Antinuclei as Messengers of New Physics: Status and Outlook for the New Decade. *JCAP*, 8(35), 2020. Available at: https://arxiv.org/abs/2002.04163.

[E42] Tegmark M Wang Y. New Light on Dark Energy. *Physics Web*, 2005. Available at: https://physicsweb.org/articles/news/8/6/14.

[E43] Tifft WG. Discrete States Of Redshift And Galaxy Dynamics I. *Astrophys J*, 206:38–56, 1976.

[E44] Wandelt BD Yadav AP. Detection of primordial non-Gaussianity (f_{NL}) in the WMAP 3-years data at above 99.5 % confidence, 2008. Available at: https://arxiv.org/abs/astro-ph/0712.1148.

Books related to TGD

[K1] Pitkänen M. Cosmology and Astrophysics in Many-Sheeted Space-Time. In *Topological Geometrodynamics: Overview: Part II.* *https://tgdtheory.fi/tgdhtml/Btgdview2.html*.

[K2] Pitkänen M. About Nature of Time. In *TGD Inspired Theory of Consciousness: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdconsc1.html*. Available at: https://tgdtheory.fi/pdfpool/timenature.pdf, 2023.

[K3] Pitkänen M. About the Nottale's formula for h_{gr} and the possibility that Planck length l_P and CP_2 length R are related. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/vzerovariableG.pdf, 2023.

[K4] Pitkänen M. About twistor lift of TGD? In *Quantum TGD: Part III.* *https://tgdtheory.fi/tgdhtml/Btgdquantum3.html*. Available at: https://tgdtheory.fi/pdfpool/hgrtwistor.pdf, 2023.

[K5] Pitkänen M. Construction of elementary particle vacuum functionals. In *p-Adic Physics.* *https://tgdtheory.fi/tgdhtml/Bpadphys.html*. Available at: https://tgdtheory.fi/pdfpool/elvafu.pdf, 2023.

[K6] Pitkänen M. Construction of Quantum Theory: Symmetries. In *Quantum TGD: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdquantum1.html*. Available at: https://tgdtheory.fi/pdfpool/quthe.pdf, 2023.

[K7] Pitkänen M. Cosmic Strings. In *Physics in Many-Sheeted Space-Time: Part II.* *https://tgdtheory.fi/tgdhtml/Btgdclass2.html*. Available at: https://tgdtheory.fi/pdfpool/cstrings.pdf, 2023.

[K8] Pitkänen M. Criticality and dark matter: part I. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/qcritdark1.pdf, 2023.

[K9] Pitkänen M. Criticality and dark matter: part II. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/qcritdark2.pdf, 2023.

[K10] Pitkänen M. Criticality and dark matter: part III. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/qcritdark3.pdf, 2023.

[K11] Pitkänen M. Criticality and dark matter: part IV. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/qcritdark4.pdf, 2023.

[K12] Pitkänen M. Does Riemann Zeta Code for Generic Coupling Constant Evolution? In *TGD as a Generalized Number Theory: Part III.* *https://tgdtheory.fi/tgdhtml/Btgdnumber3.html*. Available at: https://tgdtheory.fi/pdfpool/fermizeta.pdf, 2023.

[K13] Pitkänen M. Does TGD Predict a Spectrum of Planck Constants? In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/Planck, 2023.

[K14] Pitkänen M. Expanding Earth Model and Pre-Cambrian Evolution of Continents, Climate, and Life. In *Physics in Many-Sheeted Space-Time: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdclass1.html*. Available at: https://tgdtheory.fi/pdfpool/expearth.pdf., 2023.

[K15] Pitkänen M. General Ideas about Many-Sheeted Space-Time: Part II. In *Physics in Many-Sheeted Space-Time: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdclass1.html*. Available at: https://tgdtheory.fi/pdfpool/newviews.pdf, 2023.

[K16] Pitkänen M. Holography and Quantum Error Correcting Codes: TGD View. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/tensornet.pdf, 2023.

[K17] Pitkänen M. Knots and TGD. In *Quantum Physics as Infinite-Dimensional Geometry.* *https://tgdtheory.fi/tgdhtml/Btgdgeom.html*. Available at: https://tgdtheory.fi/pdfpool/knotstgd.pdf, 2023.

[K18] Pitkänen M. Macroscopic Quantum Phenomena and CP_2 Geometry. In *TGD and Condensed Matter.* *https://tgdtheory.fi/tgdhtml/BTGDcondmat.html*. Available at: https://tgdtheory.fi/pdfpool/super.pdf, 2023.

[K19] Pitkänen M. Massless states and particle massivation. In *p-Adic Physics.* *https://tgdtheory.fi/tgdhtml/Bpadphys.html*. Available at: https://tgdtheory.fi/pdfpool/mless.pdf, 2023.

[K20] Pitkänen M. More about TGD Inspired Cosmology. In *Physics in Many-Sheeted Space-Time: Part II.* *https://tgdtheory.fi/tgdhtml/Btgdclass2.html*. Available at: https://tgdtheory.fi/pdfpool/cosmomore.pdf, 2023.

[K21] Pitkänen M. New Physics Predicted by TGD: Part I. In *p-Adic Physics.* *https://tgdtheory.fi/tgdhtml/Bpadphys.html*. Available at: https://tgdtheory.fi/pdfpool/TGDnewphys1.pdf, 2023.

[K22] Pitkänen M. Nuclear String Hypothesis. In *TGD and Nuclear Physics.* *https://tgdtheory.fi/tgdhtml/Bnucl.html*. Available at: https://tgdtheory.fi/pdfpool/nuclstring.pdf, 2023.

[K23] Pitkänen M. p-Adic Particle Massivation: Hadron Masses. In *p-Adic Physics.* *https://tgdtheory.fi/tgdhtml/Bpadphys.html*. Available at: https://tgdtheory.fi/pdfpool/mass3.pdf, 2023.

[K24] Pitkänen M. p-Adic Physics as Physics of Cognition and Intention. In *TGD Inspired Theory of Consciousness: Part II.* *https://tgdtheory.fi/tgdhtml/Btgdconsc2.html*. Available at: https://tgdtheory.fi/pdfpool/cognic.pdf, 2023.

[K25] Pitkänen M. p-Adic Physics: Physical Ideas. In *TGD as a Generalized Number Theory: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdnumber1.html*. Available at: https://tgdtheory.fi/pdfpool/phblocks.pdf, 2023.

[K26] Pitkänen M. Quantum Astrophysics. In *Physics in Many-Sheeted Space-Time: Part II.* *https://tgdtheory.fi/tgdhtml/Btgdclass2.html*. Available at: https://tgdtheory.fi/pdfpool/qastro.pdf, 2023.

[K27] Pitkänen M. Quantum Hall effect and Hierarchy of Planck Constants. In *TGD and Condensed Matter.* *https://tgdtheory.fi/tgdhtml/BTGDcondmat.html*. Available at: https://tgdtheory.fi/pdfpool/anyontgd.pdf, 2023.

[K28] Pitkänen M. Quantum Model for Hearing. In *TGD and EEG: Part II.* *https://tgdtheory.fi/tgdhtml/Btgdeeg2.html*. Available at: https://tgdtheory.fi/pdfpool/hearing.pdf, 2023.

[K29] Pitkänen M. Self and Binding: Part I. In *TGD Inspired Theory of Consciousness: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdconsc1.html*. Available at: https://tgdtheory.fi/pdfpool/selfbindc.pdf, 2023.

[K30] Pitkänen M. TGD and Astrophysics. In *Physics in Many-Sheeted Space-Time: Part II.* *https://tgdtheory.fi/tgdhtml/Btgdclass2.html*. Available at: https://tgdtheory.fi/pdfpool/astro.pdf, 2023.

[K31] Pitkänen M. TGD and Cosmology. In *Physics in Many-Sheeted Space-Time: Part II.* *https://tgdtheory.fi/tgdhtml/Btgdclass2.html*. Available at: https://tgdtheory.fi/pdfpool/cosmo.pdf, 2023.

[K32] Pitkänen M. TGD and Potential Anomalies of GRT. In *Physics in Many-Sheeted Space-Time: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdclass1.html*. Available at: https://tgdtheory.fi/pdfpool/granomalies.pdf., 2023.

[K33] Pitkänen M. TGD as a Generalized Number Theory: Quaternions, Octonions, and their Hyper Counterparts. In *TGD as a Generalized Number Theory: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdnumber1.html*. Available at: https://tgdtheory.fi/pdfpool/visionb.pdf, 2023.

[K34] Pitkänen M. The classical part of the twistor story. In *Quantum TGD: Part III.* *https://tgdtheory.fi/tgdhtml/Btgdquantum3.html*. Available at: https://tgdtheory.fi/pdfpool/twistorstory.pdf, 2023.

[K35] Pitkänen M. The Recent Status of Lepto-hadron Hypothesis. In *p-Adic Physics.* *https://tgdtheory.fi/tgdhtml/Bpadphys.html*. Available at: https://tgdtheory.fi/pdfpool/leptc.pdf, 2023.

[K36] Pitkänen M. The Relationship Between TGD and GRT. In *Physics in Many-Sheeted Space-Time: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdclass1.html*. Available at: https://tgdtheory.fi/pdfpool/tgdgrt.pdf., 2023.

[K37] Pitkänen M. Time and Consciousness. In *TGD Inspired Theory of Consciousness: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdconsc1.html*. Available at: https://tgdtheory.fi/pdfpool/timesc.pdf, 2023.

[K38] Pitkänen M. Unified Number Theoretical Vision. In *TGD as a Generalized Number Theory: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdnumber1.html*. Available at: https://tgdtheory.fi/pdfpool/numbervision.pdf, 2023.

[K39] Pitkänen M. Was von Neumann Right After All? In *TGD and Hyper-finite Factors.* *https://tgdtheory.fi/tgdhtml/BHFF.html*. Available at: https://tgdtheory.fi/pdfpool/vNeumann.pdf, 2023.

[K40] Pitkänen M. WCW Spinor Structure. In *Quantum Physics as Infinite-Dimensional Geometry.* *https://tgdtheory.fi/tgdhtml/Btgdgeom.html*. Available at: https://tgdtheory.fi/pdfpool/cspin.pdf, 2023.

[K41] Pitkänen M. What p-Adic Icosahedron Could Mean? And What about p-Adic Manifold? In *TGD as a Generalized Number Theory: Part III.* *https://tgdtheory.fi/tgdhtml/Btgdnumber3.html*. Available at: https://tgdtheory.fi/pdfpool/picosahedron.pdf, 2023.

Articles about TGD

[L1] Pitkänen M. Further Progress in Nuclear String Hypothesis. Available at: https://tgdtheory.fi/public_html/articles/nuclstring.pdf., 2007.

[L2] Pitkänen M. Do we really understand the solar system? Available at: https://tgdtheory.fi/public_html/articles/precession.pdf., 2011.

[L3] Pitkänen M. Updated view about the hierarchy of Planck constants. *Prespacetime J.* Available at: https://prespacetime.com/index.php/pst/issue/view/34, 3(11), 2012.

[L4] Pitkänen M. CMAP representations about TGD, and TGD inspired theory of consciousness and quantum biology. Available at: https://www.tgdtheory.fi/tgdglossary.pdf., 2014.

[L5] Pitkänen M. Geometric theory of harmony. Available at: https://tgdtheory.fi/public_html/articles/harmonytheory.pdf., 2014.

[L6] Pitkänen M. Discretization and Quantum Group Description as Different Aspects of Finite Measurement Resolution. Available at: https://tgdtheory.fi/public_html/articles/qhyperbolic.pdf., 2015.

[L7] Pitkänen M. Maintenance problem for Earth's magnetic field. Available at: https://tgdtheory.fi/public_html/articles/Bmaintenance.pdf., 2015.

[L8] Pitkänen M. Variation of Newton's constant and of length of day. Available at: https://tgdtheory.fi/public_html/articles/Newtonday.pdf., 2015.

[L9] Pitkänen M. Cyclic cosmology from TGD perspective. Available at: https://tgdtheory.fi/public_html/articles/turok.pdf., 2016.

[L10] Pitkänen M. How the hierarchy of Planck constants might relate to the almost vacuum degeneracy for twistor lift of TGD? Available at: https://tgdtheory.fi/public_html/articles/hgrtwistor.pdf., 2016.

[L11] Pitkänen M. Hydrinos again. Available at: https://tgdtheory.fi/public_html/articles/Millsagain.pdf., 2016.

[L12] Pitkänen M. Number theoretical feats TGD inspired theory of consciousness. Available at: https://tgdtheory.fi/public_html/articles/numberfeats.pdf., 2016.

[L13] Pitkänen M. Strong support for TGD based model of cold fusion from the recent article of Holmlid and Kotzias. Available at: https://tgdtheory.fi/public_html/articles/holmilidnew.pdf., 2016.

[L14] Pitkänen M. TGD Inspired Comments about Integrated Information Theory of Consciousness. Available at: https://tgdtheory.fi/public_html/articles/tononikoch.pdf., 2016.

[L15] Pitkänen M. Cold fusion, low energy nuclear reactions, or dark nuclear synthesis? Available at: https://tgdtheory.fi/public_html/articles/krivit.pdf., 2017.

[L16] Pitkänen M. About the physical interpretation of the velocity parameter in the formula for the gravitational Planck constant . Available at: https://tgdtheory.fi/public_html/articles/vzero.pdf., 2018.

[L17] Pitkänen M. Conformal cyclic cosmology of Penrose and zero energy ontology based cosmology. Available at: https://tgdtheory.fi/public_html/articles/ccctgd.pdf., 2018.

[L18] Pitkänen M. Expanding Earth Model and Pre-Cambrian Evolution of Continents, Climate, and Life. Available at: https://tgdtheory.fi/public_html/articles/expearth.pdf., 2018.

[L19] Pitkänen M. Morphogenesis in TGD Universe. Available at: https://tgdtheory.fi/public_html/articles/morphoTGD.pdf., 2018.

[L20] Pitkänen M. TGD view about quasars. Available at: https://tgdtheory.fi/public_html/articles/meco.pdf., 2018.

[L21] Pitkänen M. Copenhagen interpretation dead: long live ZEO based quantum measurement theory! Available at: https://tgdtheory.fi/public_html/articles/Bohrdead.pdf., 2019.

[L22] Pitkänen M. Could Mars have intra-planetary life? Available at: https://tgdtheory.fi/public_html/articles/Mars.pdf., 2019.

[L23] Pitkänen M. Earhquakes and volcanic eruptions as macroscopic quantum jumps in zero energy ontology. Available at: https://tgdtheory.fi/public_html/articles/earthquakes.pdf., 2019.

[L24] Pitkänen M. Solar Metallicity Problem from TGD Perspective. Available at: https://tgdtheory.fi/public_html/articles/darkcore.pdf., 2019.

[L25] Pitkänen M. Solar Surprise. Available at: https://tgdtheory.fi/public_html/articles/solarsycle.pdf., 2019.

[L26] Pitkänen M. Some solar mysteries. https://tgdtheory.fi/public_html/articles/Haramein.pdf., 2024.