Quantum Astrophysics

M. Pitkänen,

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Email: matpitka6@gmail.com.
http://tgdtheory.com/public_html/.
Postal address: Rinnekatu 2-4 A 8, 03620, Karkkila, Finland. ORCID: 0000-0002-8051-4364.

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Abstract

In this chapter the topics relates to what might be called quantum astrophysics. Motivation comes from the model for Nottale's findings suggesting Bohr quantization of planetary orbits. The model leads to the introduction of gravitational Planck constant $h_{gr} = GMm/v_0$, where v_0 corresponds to a typical rotational velocity in two particle system. h_{gr} characterizes the interaction of masses M and m and assigned to the magnetic flux tube connecting them and carrying the massless extremals mediating gravitational interaction. If m is planetary mass, the value of h_{gr} is gigantic. Since gravitational acceleration and gravitational Compton length do not depend on particle mass, one can however assume only that microscopic objects have gravitational flux tube connections to the central mass M. In this case the values of h_{gr} could be even identical to the corresponding values of $h_{eff} = n \times h$ in living matter and $h_{eff} = h_{gr}$ identification makes sense.

The topics discuss in this chapter are following.

1. An updated view about hierarchy of Planck constants is discussed and the connection $h_{eff} = h_{gr}$ is shown to be consistent with TGD inspired quantum biology. Quantum gravity would be in key role in biology as intuited also by Penrose.
2. Vision about formation of structures and quantum chaos is astrophysical scales is discussed. Also a speculative view about gravitational radiation based on h_{gr} is considered.
3. A simple model for gravitational radiation assuming that the emission occurs as dark gravitons is considered. $h \rightarrow h_{gr}$ implies that the energy of graviton is scaled from that in standard model by h_{gr}/h factor. Realistic model might correspond to h_{gr} for microscopic particles. The basic prediction is that gravitons would be detected as bunches of ordinary gravitons.
4. TGD suggests that cosmological evolution involves a series of phase transitions changing the value of h_{gr} occurring via periods of quantum criticality. The critical cosmology is fixed apart from its duration. This suggests a piecewise accelerated expansion. Also inflationary period would be example of this phenomenon as also accelerating expansion much later.
5. Expanding Earth model has been proposed for long time ago to explain why the continents seem to fit nicely to form a complete covering of the Earth's surface. The model however makes sense if the radius of Earth is one half of its recent value. TGD based interpretation for the expansion is is in terms of a phase transition increasing h_{gr} by factor 2.
6. Blackholes in TGD is the topic of the last two sections.

1 Introduction

The mechanisms behind the formation of planetary systems, galaxies and larger systems are poorly understood but planar structures seem to define a common denominator and the recent discovery of dark matter ring in a galactic cluster in Mly scale [E19] suggest that dark matter rings might define a universal step in the formation of astrophysical structures.

Also the dynamics in planet scale is poorly understood. In particular, the rings of Saturn and Jupiter are very intricate structures and far from well-understood. Assuming spherical symmetry it is far from obvious why the matter ends up to form thin rings in a preferred plane. The latest surprise [E9] is that Saturn's largest, most compact ring consist of clumps of matter separated by almost empty gaps. The clumps are continually colliding with each other, highly organized, and heavier than thought previously.

The situation suggests that some very important piece might be missing from the existing models, and the vision about dark matter as a quantum phase with a gigantic Planck constant [K16] is an excellent candidate for this piece. The vision that the quantum dynamics for dark matter is behind the formation of the visible structures suggests that the formation of the astrophysical structures could be understood as a consequence of Bohr rules [K23].

1.1 Generalization Of The Notion Of Imbedding Space

Quite generally, the hierarchy of Planck constants is realized by generalizing the notion of embedding space such that one has a book like structure with various almost-copies of embedding space glued together like pages of book. Each page of book correspond to a particular level of dark matter hierarchy and darkness means that there are no Feynman diagrams in which particles with different value of Planck constant would appear. The interactions between different levels of hierarchy involve the transfer of the particles mediating the interaction between different pages of the book. Physically this means a phase transition changing the value of Planck constant assignable to the particle so that particle's quantum size is scaled. At classical level the interactions correspond to the leakage of magnetic and electric fluxes and radiation fields between different pages of the book.

1.1.1 The development of the view about generalized imbedding space

The development of precise formulation of the realization of Planck constants in terms of the book like structure of embedding space has been a sequence of improved trials.

1. Since space-time surfaces are 4-surfaces in the generalized embedding space, Bohr rules can be formulated in a way which is general coordinate invariant and Lorentz invariant. The rules are actually for dark matter structures obeying Z_n symmetry for very large n characterizing a symmetry of field bodies associated with the structure in question. Z_n was identified as a maximal cyclic subgroup for any subgroup $G \subset SO(3)$ appearing in the series of Jones inclusions with index $\mathcal{M}/\mathcal{N} < 4$ but also $\mathcal{M}/\mathcal{N} \geq 4$ can be considered. Two questions arise. What distinguishes between these two cases and what is the precise action of G.

2. The first generalization of the embedding space assigned Z_n to rotations in M^4 degrees of freedom acting as symmetries of factor space obtained dividing with subgroup of $G \subset SO(3)$ having Z_n as maximal cyclic subgroup. The outcome was a book like structure associated with $M^4\backslash M^2$ with M^2 defining the back of the book and characterizing the direction of quantization axes for spin. The choice of M^2 has interpretation as fixing choice of the direction of quantization axes. The world of classical worlds (WCW) would be union over different choices of M^2.

3. This generalization was not enough to really understand the physics behind gravitational Planck constant, and the next generalization assigned the groups associated with Jones inclusions also with CP_2 degrees of freedom and acting also now as invariance group of orbifold structure associated with CP_2. In CP_2 degrees of freedom the back of the book is defined by homologically trivial geodesic sphere S^2 of CP_2. Therefore one has book like structure in both M^4 and CP_2 degrees of freedom.

4. The attempts to understand Quantum Hall effect suggested a generalization, which allowed both factor spaces and coverings of both M^4 and CP_2. In the case of coverings the action of Z_n contained by the group assignable to Jones inclusion permutes the sheets of the singular covering space of $M^4\backslash M^2$ ($CP_2\backslash S^2$). In the similar way the group acts in the singular factor space associated with $M^4\backslash M^2$ ($CP_2\backslash S^2$). The coverings were assigned with Jones inclusions having index $\mathcal{M}/\mathcal{N} \geq 4$.

5. The emergence of zero energy ontology induced further detail to this picture. In zero energy ontology causal diamond (CD) of M^4 defined as the intersection of future and past directed light-cones is basic structure. $CD \times CP_2$ contains positive (negative) energy parts of the zero energy state at the lower (upper) light-like boundary δM^4_+ δM^4_-. Each CD defines sector in the world of classical worlds (WCW) consisting of light-like 3-surfaces and corresponding 4-surfaces inside $CD \times CP_2$. Each sector of this kind in turn corresponds a union over copies of CDs corresponding to different choices of quantization axes for Poincare and color quantum numbers so that the selection of quantization axis means a localization to one particular variant of given CD. Temporal and spatial localization in turn fixes the lower tip of CD: the location of upper tip is fixed by the condition that the temporal distance between upper and lower tip is quantized in powers of two: this assumption implies p-adic length scale hypothesis. The singular covering and factor spaces of CD:s become the pages of the book like structures. One can say that these books are like rigid bodies located in $M^4 \times CP_2$ and that they have also rotational and color rotational degrees of freedom so that WCW is kind of gigantic quantum library.

6. The most tortuous piece of the tortuous development of the ideas were the guesses for the formula for Planck constant in terms of integers n_a and n_b characterizing the orders of maximal cyclic subgroups of G_a and G_b. The realization that the formula could be interpreted as homomorphism from the set of pages of the book left still two options for which expressions for the Planck constant were inverses of each other. Four options are possible and it seems that the correct option was found in the fourth trial! A heuristic argument based on $1/\hbar$ proportionality of the fine structure constant combined with the earlier condition that Compton length is proportional to n_a led to what I believe is the correct formula. For the Cartesian product of n_a resp. n_b-fold coverings of CD and CP_2 one has $\hbar = n_a n_b$. When covering is replaced with a factor space, n_i goes to $1/n_i$ in the formula. The model for quantum Hall effect is consistent with this [K22]. and this option is also favored by the gravitational Bohr orbitology and the model for dark graviton emission. The notion of generalized embedding space is describe in detail in Appendix.

7. For this identification of the Planck constant the huge value of h_{gr} requires that CD or CP_2 or both correspond to a singular covering space. These options can be denoted by $C-C$, $C-F$ and $F-C$. Rotational symmetries Z_{n_a} with small n_a are possible for $F-C$ option for very large value of n_b. For $C-F$ option dark matter symmetries with large Z_n acts in the covering of CD so that no discrete rotational invariance in CD is predicted. The $F-F$ option for which both G_a and G_b act as orbifold symmetries is not favored in gravitation nor living matter since one $\hbar/\hbar_0 = 1/n_a n_b$.

1.1.2 The extension of embedding space to a book-like structure

The allowance of coverings means an extension of the embedding space by allowing also G_a *resp.* G_b-fold coverings of $\hat{CD} = CD\backslash M^2$ *resp.* $\hat{CP}_2 = CP_2\backslash S^2$. Here M^2 corresponds to 2-D Minkowski space defined by the fixing of rest frame and direction of quantization axis of angular momentum and S^2 to a homologically trivial geodesic sphere of CP_2 which corresponds to a particular choice of group $SO(3) \subset SU(3)$ and thus fixing of quantization axes of color isospin. The surfaces $X^4 \subset M^4 \times S^2$ are vacuum extremals as required by internal consistency of the theory. The leakage between different pages of book occurs via manifolds $CD \times S^2$ and $(M^2 \cap CD) \times CP_2$ which correspond to quantum criticality. The extreme form of quantum criticality corresponds to leakage through $M^2 \times S^2$.

There are four options corresponding to $C-C$, $F-F$, $C-F$ and $F-C$.

1. Options $C-C$ and $C-F$ for which G_a acts in the covering space of CD are perhaps the most promising candidates for the modelling of dark gravitons and gravitational Bohr orbitology but also $F-C$ option can be considered. $C-C$ maximizes the value of $\hbar$. Also fractional quantum Hall effect is possible only for these options (see Appendix). These options allow large values of Planck constant and could be involved also with living matter.

2. G_a could act as factor space symmetries in living matter for $F-C$ option. Molecular rotational symmetries correspond typically to small groups G_a $G_a = Z_n$, $n = 5, 6$ are favored for molecules containing aromatic cycles and could correspond to factor spaces in M^4 degrees of freedom and coverings in CP_2 degrees of freedom ($r = n_b/n_a$). Also genuinely 3-dimensional tetrahedral, octahedral, and icosahedral symmetries appear in living matter. Even the symmetries of snow flakes could be understood for $F-C$ option if n_b is large enough so that quantum scale proportional to n_b/n_a is macroscopic.

3. Also astrophysical systems might possess small G_a as orbifold symmetries and one an ask whether the hexagonal structure at the North Pole of Saturn could be an example of $n_a = 6$ fold symmetry. One must remember that these symmetries are exact at the level of dark matter but need not be so at the level of visible matter.

It must be emphasized that this interpretation differs quite a lot from the earlier ones which assumed different formulae of Planck constant.

1.1.3 Does the hierarchy follow from the basic quantum TGD?

One can consider also the possibility that the hierarchy of Planck constants follows from the basic quantum TGD rather than being assumed as a separate postulate. The argument goes as follows.

1. By the extreme non-linearity of the Kähler action the correspondence between the time derivatives of the embedding space coordinates and canonical momentum densities is many-to-one. This leads naturally to the introduction of covering spaces of $CD \times CP_2$, which are singular in the sense that the sheets of the covering co-incide at the ends of CD and at wormhole throats. One can say that quantum criticality means also the instability of the 3-surfaces defined by the throats and the ends against the decay to several space-time sheets and consequent charge fractionization. The interpretation is as an instability caused by too strong density of mass and making perturbative description possible since the matter density at various branches is reduced. The nearer the vacuum extremal the system is, the lower the mass density needed to induce the instability is and the larger is the number of sheets resulting in this way is.

2. The singular regions of the covering are regions in which the integer characterizing the multiple-valuedness of the time derivatives of the embedding space coordinates as functions of canonical momentum densities is reduced from the maximal value. The reduction to single sheeted covering could (but need not!) take place over any Lagrangian manifold of CP_2 rather than only over a homologically trivial geodesic sphere and would thus directly correspond to the vacuum degeneracy of Kähler action. One can also imagine the reduction of the integer characterizing multi-valuedness to a smaller value different from one in non-vacuum regions.

3. In M^4 degrees of freedom branching to a single sheeted covering can occur over any partonic 2-surface which does not enclose the tip of CD. In this case the Kähler gauge potential would contain a singular gauge term having an archetypal form $\Delta A = d\phi/n_a$ at say upper hemisphere so that the magnetic flux would receive a non-vanishing contribution from North pole and give rise to a fractionized Kähler magnetic and therefore also to Kähler electric charge. This term is pure gauge for all partonic 2-surface not containing the tip of CD. Thus one species of anyons would be associated with this kind of partonic 2-surfaces. Second species would correspond to singular gauge transforms about which example would be $\Delta A = d\Psi/n_b$, where Ψ is the angle coordinate associated with a homologically non-trivial geodesic sphere. The modification of the Kähler gauge potential could be interpreted in terms of a measurement interaction term added to the Dirac action and their sum at the ends would give rise to the non-fractional contribution to the measurement interaction term. This kind of term would be also associated with Noether charges such as 4-momentum. Depending on whether one considers the end of space-time sheet or at wormhole throat, the measurement interaction term would be given as $1/n_b$ or $1/n_a$ multiple of the measurement interaction term in absence of branching and would be more complex than the simple archetypal forms.

4. Classically the fractional Noether charges would emerge from Chern-Simons representation of Kähler function with the Lagrangian multiplier term realizing the weak form of electric-magnetic duality as a constraint. The latter term would be responsible for the non-vanishing values of four-momentum and angular momentum. The isometry charges in CP_2 degrees of freedom would receive a contribution also from the Chern-Simons term.

5. The situation can be described mathematically either by using effectively only single sheet but an integer multiple of Planck constant or many-sheeted covering and ordinary value of Planck constant. In [K16] the argument that this indeed leads to hierarchy of Planck constants including charge fractionization is developed in detail. The restriction to singular coverings is consistent with the experimental constraints and means that only integer valued Planck constants are possible. A given value of Planck constant corresponds only to a finite number of the pages of the Big Book and that the evolution by quantum jumps is analogous to a diffusion at half-line and tends to increase the value of Planck constant.

6. The following argument would suggest a direct connection between vacuum degeneracy, coverings, and the hierarchy of infinite primes. For vacuum extremal the number of sheets is

formally infinite but the sheets are in a well-define sense "passive". The numbers n_a and n_b for sheets correspond to powers p^{n_a} and p^{n_b} for a prime appearing in infinite prime characterizing the partonic 3-surface and having interpretation as particle numbers. The unit infinite primes $X \pm 1$ correspond to the two basic infinite primes having interpretation as fermionic vacua are interpreted as Dirac sea: the numbers of bosons and fermions are vanishing for them. This suggests that the fermions of Dirac sea correspond to the "passive" sheets. This raises the question whether one could characterize the infinite degeneracy associated with vacuum extremals by these two infinite primes and non-vacuum extremals by infinite primes for which boson and fermion numbers are non-vanishing. The two infinite primes would correspond to CD and CP_2 degrees of freedom. They could also correspond to the space-time sheets of Euclidian and Minkowskian signature of the induced metric meeting at the wormhole throat at which the induced 4-metric is degenerate. Bose-Einstein condensate of n_i bosons ($i = a, b$) or fermion plus $n_i - 1$ bosons would correspond to n_i sheets of covering.

Arithmetic quantum field theory allows infinite number of conservation laws corresponding to the conservation of the number theoretic momentum $p = \sum_i n_i log(p_i)$ which forces separate conservation of each number theoretical momentum $n_i log(p_i)$ since the logarithms of primes are linearly independent in the realm of rationals. This conservation law could correlate the partonic lines arriving in the interaction vertices and state that the total number of sheets of the covering is conserved although it can be shared by several partonic space-time sheets in the final state.

The reduction of the hierarchy of Planck constants to basic quantum TGD is of course only an interesting idea and the best strategy to proceed is to develop objections against it.

1. The branching of partonic 2-surfaces at the ends of space-time sheets and wormhole throats is analogous to the branching of the line of Feynman graph. The 3-D lines of generalized Feynman graphs indeed branch at the vertices and this leads to the basic objection against the proposed interpretation of the fractionization. Could one consider the possibility that branching corresponds to what happens in the vertices of Feynman diagrams? This cannot not seem to be the case. The point is that canonical momentum densities are identical so that also the conserved classical Noether and Kähler charges associated with various branches should be the same.

2. The value of gravitational Planck constant is enormous and one would mean enormously many-fold branching of partonic 2-surfaces of astrophysical size. Does this really make sense? Is this simply due the fact that the basic parameter GM_1M_2 characterizing the strength of gravitational interaction is much larger than unity so that perturbation theory in terms of it fails to converge and the splitting to $\hbar_{gr}/\hbar_0$ sheets guarantees that the perturbation theory at each sheet converges.

3. One can also ask whether the fractional charges can be observed directly since it seems that only the partonic 2-surfaces at the ends of the space-time sheet are observable.

4. Perhaps the most serious objection relates to the basic intuition about scaling of quantum lengths by $\hbar$ since this scaling is fundamental for all predictions in the model of quantum biology. It is not obvious why the basic quantum lengths in M^4 degrees of freedom - in particular the size scale of CD - should be scaled up by n_an_b. Could this scaling up result dynamically or can one find some simple kinematic argument forcing the size scale spectrum of CDs? Kinematic argument is more plausible and indeed exists. Suppose that one can speak about plane waves $exp(inEt/\hbar_0)$, where t is proper time coordinate associated with the line connecting the tips of CD. Periodic boundary conditions at $t = T$ imply $E = n\hbar_0/2\pi T$ where T is the proper time distance between the tips of CD. Suppose that $\hbar_0$ is replaced with its n_an_b multiple in the plane wave. As a consequence, the plane waves for sheets and for same value of E do not anymore satisfy periodic boundary conditions at $t = T$ anymore. These conditions are however satisfied for $t = n_an_bT$.

Equivalence Principle allows also to assume the formula for h_{gr} to apply for elementary particles only but does not exclude it in longer scales. The restriction to elementary particle and atomic scales supports to the identification $h_{gr} = h_{eff}$ unifying the two views to the hierarchy of Planck constants inspired by Nottale's findings on one hand, and by tge effects of ELF em fields on vertebrate brain on the other hand. The gravimagnetic anomaly proposed by Tajmar *et al* [E20, E24] gives support for this identification [K25], and leads to rather detailed view about the role of large h_{eff} phases in TGD inspired quantum biology.

1.2 Gravitational Bohr Orbitology

The basic question concerns justification for gravitational Bohr orbitology. The basic vision is that visible matter identified as matter with $\hbar = \hbar_0$ ($n_a = n_b = 1$) concentrates around dark matter at Bohr orbits for dark matter particles. The question is what these Bohr orbits really mean. Should one in the improved approximation relate Bohr orbits to 3-D wave functions for dark matter as ordinary Bohr rules would suggest or do the Bohr orbits have some deeper meaning different from that in wave mechanics.

1.2.1 The first vision

The first vision about gravitational Bohr orbitology was inspired by the finding that surprisingly complex geometric structures possessing relatively small subgroups of rotational group as approximate symmetry groups appear in astrophysical scales (say the hexagonal structure associated with Saturnus). This would suggest circles and spokes representing dark matter structures, gravi-electric flux quanta, and also circles representing gravi-magnetic flux tubes orthogonal to the quantization plane become are building blocks of dark matter structures. This makes sense for $F - C$ option and the group G_a acting as orbifold symmetries would be behind these symmetries. This would require very large G_b acting as covering space symmetry in CP_2 degrees of freedom. Simplest of these structures are rings and cart-wheel like structures with rather small symmetry groups which are however badly broken. One could however argue that this breaking occurs only at the level of visible way.

Z_{n_a} would act as rotational symmetries of magnetic body and its subgroups could act as approximate symmetries of the visible matter and if one accepts ruler-and-compass hypothesis powerful predictions follow. On the other hand,

This option works nicely in the case of quantum Hall effect if spin fractionization is involved. If one assumes that the dark space-time sheets associated with gravitons and matter correspond to same page of the Big Book, this picture leads to difficulties since large n_b for covering and small n_a for orbifold does not lead to a plausible picture about what dark gravitons should be.

1.2.2 Quantum criticality and quantum chaos

TGD Universe is quantum critical and quantum criticality corresponds very naturally to what has been identified as the transition region to quantum chaos. The basic formulation of quantum TGD is indeed consistent with what has been learned from the properties of quantum chaotic systems and quantum chaotic scattering [B7]. Wave functions are concentrated around Bohr orbits in the limit of quantum chaos, which is just what dark matter picture assumes. In this framework the chaotic motion of astrophysical object becomes the counterpart of quantum chaotic scattering and classical description is predicted to fail. By Equivalence Principle the value of the mass of the object does not matter at all so that the motion of sufficiently light objects in solar system might be understandable only as quantum chaotic scattering. The motion of gravitationally unbound comets and rings of Saturn and Jupiter and the collisions of galactic structures known to exhibit the presence of cart-wheel like structures define possible applications.

The description of gravitational radiation provides a stringent test for the idea about dark matter hierarchy with arbitrary large values of Planck constants. In accordance with quantum classical correspondence, one can take the consistency with classical formulas as a constraint allowing to deduce information about how dark gravitons interact with ordinary matter. The standard facts about gravitational radiation are discussed first and then TGD based view about the situation is sketched in two cases corresponding to large value of n_a characterizing singular CD covering or orbifold and n_b characterizing singular CP_2 covering.

This discussion forces an important conclusion. The sequential de-coherence leading from dark gravitons with $(n_a > 1, n_b > 1)$ in stepwise way to visible gravitons having $(n_a = 1, n_b = 1)$ necessary involves steps in which the frequency of the resulting lower level gravitons is subharmonic of the original frequency. Ruler and compass hypothesis favors period doubling since powers of two are favored for n_a and n_b. The generation of sub-harmonics is one of the basic routes to chaos which suggests that chaos in astrophysical systems corresponds to large values of n_b with powers of 2 favored. Quite generally, the approach to quantum chaos would transform $\hbar/\hbar_0$ from integer to a rational with increasing denominator.

The planetary Bohr orbitology has been already discussed in the chapter "TGD and Astrophysics" [K23] with applications solar system and exo-planets. This discussion is not based on the full generalization of the embedding space but the general results are not changed since they depend on the value of Planck constant only. Instead of repeating this discussion, a formulation of these rules which is general coordinate invariant and Lorentz invariant is proposed.

1.2.3 About the spectrum of v_0

The proposed generalization of the embedding space allows in principle any rational multiple of $\hbar_0$ as the value of Planck constant and given value of Planck constant is realized by very many pages of the book like structure. For instance, for $F-C$ and $C-F$ options all integer multiples of (n_a, n_b) produce the same Planck constant.

The dependence of the gravitational Planck constant on masses is fixed by Equivalence Principle. Its strongest form would require a universal value of $v_0/c \equiv v_0$ (although in the following units with $c = 1$ are used, it is important to remember that v_0 is basically velocity like parameter). This form is not realized.

1. Different value of v_0 is required for inner and outer planets. I have discussed a simple model explaining why inner and outer planets must have different values of v_0 by taking into account cosmic string contribution to the gravitational potential which is negligible nowadays but was not so in primordial times. Among other things this implies that planetary system has a finite size, at least about 1 ly in case of Sun (nearest star is at distance of 4 light years). The proposed anyonic picture would suggest that the anyonic 2-surface assignable to outer and inner planets is different.

2. Quantization rules have been applied to exoplanets in the case that the central mass and orbital radius are known (the discussion is moved from the chapter "Astrophysics" to the the Appendix of this chapter). Errors are around 10 per cent for the most favored value of $v_0 = 2^{-11}$. The "anomalous" planets with very small orbital radius correspond to $n = 1$ Bohr orbit ($n = 3$ is the lowest orbit in solar system). The universal velocity spectrum $v = v_0/n$ in simple systems perhaps the most remarkable prediction and certainly testable: this alone implies that the Bohr radius GM/v_0^2 defines the universal size scale for systems involving central mass. Obviously this is something new and highly non-trivial.

3. The recently observed dark ring in MLy scale is a further success and also the rings and Moons of Saturn and Jupiter obey the same universal length scale ($n \geq 5$ and $v_0 \to (16/15) \times v_0$ and $v_0 \to 2 \times v_0$).

4. For our own Moon orbital radius is much larger than Bohr radius for $v_0 = 2^{-11}$: one would have $n \simeq 138$. $n \simeq 7$ results for $v_0 \to v_0/20$ giving $r_0 \simeq 1.2 R_E$. The small value of v_0 could be understood to result from a sequence of phase transitions reducing the value of v_0 to guarantee that solar system participates in the average sense to the cosmic expansion and from the fact inner planets are older than outer ones in the proposed scenario. The findings of Masreliez [E13] discussed in the last section of [K23] support the prediction that planetary system does not participate cosmic expansion in a smooth way.

The question becomes how to explain what is the correct way to weaken Equivalence Principle and why the values of v_0 are what they are. The simplest hypothesis is that v_0 has a fixed value for orbits connected by radial flux tubes to a given anyonic 2-surface. If the value of v_0 characterizes different anyonic 2-surfaces to which flux tubes around planetary orbits are connected by radial flux tubes then inner and outer planets would correspond to different anyonic two-surfaces. This would also give a precise characterization for the weakened form of Equivalence Principle. One could see outer planets as planets of the central object formed by Sun and inner planets. This picture would raise spherical surface at the distance of Earth to a very special role as the boundary of this central object and one can wonder whether the very special properties of Earth relate to this special role.

Planetary Bohr orbitology was born as a generalization of atomic Bohr orbitology. One can however turn the situation upside down and ask whether also atom could be seen as an anyonic system in which flux tubes surrounding classical electronic orbits are connected to an anyonic 2-surface assignable to nucleus by radial flux tubes mediating Coulomb interaction. Charge and spin fractionization do not support this idea and anyonic systems are also many-particle systems. It is indeed quite conceivable that atoms in electrons corresponds to CP_2 sized partonic 2-surfaces with atomic wave function assignable to the position of this 2-surface in the interior of larger 3-surface.

There is still one question to be considered. Could one understand why the values of v_0 are what they are?

1. The condition that $\hbar = GM^2/v_0$ gives for the dark Planck length $L_P = \sqrt{\hbar G}$ a value of order Schwartschild radius $r_S = 2GM$ forces $v_0 = 1/4$. The Planck length for $\hbar = GM(sun)M(Planet)/v_0$ corresponds to

$$L_P(\hbar) = \sqrt{\frac{r_S(Sun)r_S(Planet)}{4v_0}} = r_S(Sun)\sqrt{\frac{M(Planet)}{M(Sun)}}\sqrt{\frac{1}{4v_0}} \ .$$

The smaller mass of planet is compensated by the smallness of v_0 so that $G(\hbar)$ is not too far from $r_S(Sun)$: maybe this condition might fix at least the order of magnitude of v_0 somehow. In the case of Earth and Jupiter having $v_0 = 2^{-11}/5$ one has $G(\hbar) \simeq .27 r_S(Sun)$ and $G(\hbar) \simeq 1.6 r_S(Sun)$.

2. One can also try to find justification for why just $v_0 = 2^{-11}$ is preferred for inner planets. By Bohr quantization v_0 corresponds to a typical rotational velocity of mass m with respect to the cm of mass M. This gives a good idea about feasible values of v_0. This number also happens to correspond to the rotation velocity v/c of matter around cosmic string like objects assignable to galaxies and is expressible in terms of basic constants of quantum TGD (CP_2 length and Kähler coupling strength) appearing in the expression of string tension of cosmic strings.

1.3 How General Coordinate Invariance And Lorentz Invariance Are Achieved?

The basic objection of General Relativist against the planetary Bohr orbitology model is the lack of the manifest General Coordinate invariance and Lorentz symmetry. In GRT context this objection would be fatal. In TGD framework the lack of these symmetries is only apparent.

One can use Minkowski coordinates of the M^4 factor of the imbedding space $H = M^4 \times CP_2$ as preferred space-time coordinates. The basic aspect of dark matter hierarchy is that it realizes quantum classical correspondence at space-time level by fixing preferred M^4 coordinates as a rest system. This guarantees preferred time coordinate and quantization axis of angular momentum. The physical process of fixing quantization axes thus selects preferred coordinates and affects the system itself at the level of space-time, embedding space, and configuration space (world of classical worlds). This is definitely something totally new aspect of observer-system interaction.

One can identify in this system gravitational potential Φ_{gr} as the g_{tt} component of metric and define gravi-electric field E_{gr} uniquely as its gradient. Also gravi-magnetic vector potential A_{gr} and and gravi-magnetic field B_{gr} can be identified uniquely.

1.3.1 Quantization condition for simple systems

Consider now the quantization condition for angular momentum with Planck constant replaced by gravitational Planck constant $\hbar_{gr} = GMm/v_0$ in the simple case of point like central mass. The condition is

$$m\oint v \bullet dl \quad = \quad n \times \hbar_{gr} \quad . \tag{1.1}$$

The condition reduces to the condition on velocity circulation

$$\oint v \bullet dl \quad = \quad n \times \frac{GM}{v_0} \quad . \tag{1.2}$$

In simple systems with circular orbits the condition reduces to a universal velocity spectrum $v = v_0/n$ so that only the radii of orbits depend on mass distribution. For systems for which cosmic string dominates only $n = 1$ is possible. This is the case in the case of stars in galactic halo if primordial cosmic string going through the center of galaxy in direction of jet dominates the gravitational potential. The velocity of distant stars is correctly predicted.

For circular orbits there is no need to apply the condition for other canonical momenta (radial canonical momentum in Kepler problem). The nearly circular orbits of visible matter objects would be naturally associated with dark matter rings or more complex structures dark matter rings could suffer partial or complete phase transition to visible matter.

1.3.2 Generalization of the quantization condition

By Equivalence Principle dark ring mass disappears from the quantization conditions and the left hand side of the quantization condition equals to a generalized velocity circulation applying when central system rotates

$$\oint (v - A_{gr}) \bullet dl. \tag{1.3}$$

Note that the geodesic motion of visible matter does not mean closed orbit (perihelion shift of Mercury) and cannot therefore correspond exactly to a motion concentrated at partonic 2-surface containing anyonic dark matter unless dark matter itself is rotating slowly. This is not a problem if the dark matter is concentrated at flux tube surrounding the orbit in turn connected by flux tubes to an anyonic 2-surface assignable to Sun.

The right hand side of the quantization condition would be the generalization of GM by the replacement

$$GM \rightarrow \oint e \bullet r^2 E_{gr} \times dl. \tag{1.4}$$

e is a unit vector in direction of quantization axis of angular momentum, $\times$ denotes cross product, and r is the radial M^4 coordinate in the preferred system. Everything is Lorentz and General Coordinate Invariant and for Schwartschild metric this reduces to the expected form and reproduces also the contribution of cosmic string to the quantization condition correctly.

1.4 Topics Of The Chapter

The topics discuss in this chapter are following.

1. An updated view about hierarchy of Planck constants is discussed and the connection $h_{eff} = h_{gr}$ is shown to be consistent with TGD inspired quantum biology. The implication is that quantum gravity would be in key role in biology as intuited also by Penrose.

2. Vision about formation of structures and quantum chaos is astrophysical scales is discussed. Also a speculative view about gravitational radiation based on h_{gr} is considered.

3. TGD suggests that cosmological evolution involves a series of phase transitions changing the value of h_{gr} occurring via periods of quantum criticality. The critical cosmology is fixed apart from its duration. This suggests a piecewise accelerated expansion. Also inflationary period would be example of this phenomenon as also accelerating expansion much later.

4. Expanding Earth model has been proposed for long time ago to explain whyt the continents seem to fit nicely to form a complete covering of the Earth's surface. The model however makes sense if the radius of Earth is one half of its recent value. TGD based interpretation for the expansion is is in terms of a phase transition increasing h_{gr} by factor 2.

5. Blackholes in TGD is the topic of the last two sections.

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` [L3].

2 Updated View About The Hierarchy Of Planck Constants

The original hypothesis was that the hierarchy of Planck constants is real. In this formulation the embedding space was replaced with its covering space assumed to decompose to a Cartesian product of singular finite-sheeted coverings of M^4 and CP_2.

Few years ago came the realization that it could be only effective but have same practical implications. The basic observation was that the effective hierarchy need not be postulated separately but follows as a prediction from the vacuum degeneracy of Kähler action. In this formulation Planck constant at fundamental level has its standard value and its effective values come as its integer multiples so that one should write $\hbar_{eff} = n\hbar$ rather than $\hbar = n\hbar_0$ as I have done. For most practical purposes the states in question would behave as if Planck constant were an integer multiple of the ordinary one. In this formulation the singular covering of the embedding space became only a convenient auxiliary tool. It is no more necessary to assume that the covering reduces to a Cartesian product of singular coverings of M^4 and CP_2 but for some reason I kept this assumption.

The formulation based on multi-furcations of space-time surfaces to N branches. For some reason I assumed that they are simultaneously present. This is too restrictive an assumption. The N branches are very much analogous to single particle states and second quantization allowing all $0 < n \leq N$-particle states for given N rather than only N-particle states looks very natural. As a matter fact, this interpretation was the original one, and led to the very speculative and fuzzy notion of N-atom, which I later more or less gave up. Quantum multi-furcation could be the root concept implying the effective hierarchy of Planck constants, anyons and fractional charges, and related notions- even the notions of N-nuclei, N-atoms, and N-molecules.

2.1 Basic Physical Ideas

The basic phenomenological rules are simple and there is no need to modify them.

1. The phases with non-standard values of effective Planck constant are identified as dark matter. The motivation comes from the natural assumption that only the particles with the same value of effective Planck can appear in the same vertex. One can illustrate the situation in terms of the book metaphor. Embedding spaces with different values of Planck constant form a book like structure and matter can be transferred between different pages only through the back of the book where the pages are glued together. One important implication is that light exotic charged particles lighter than weak bosons are possible if they have non-standard value of Planck constant. The standard argument excluding them is based on decay widths of weak bosons and has led to a neglect of large number of particle physics anomalies [K28].

2. Large effective or real value of Planck constant scales up Compton length - or at least de Broglie wave length - and its geometric correlate at space-time level identified as size scale of the space-time sheet assignable to the particle. This could correspond to the Kähler magnetic flux tube for the particle forming consisting of two flux tubes at parallel space-time sheets and short flux tubes at ends with length of order CP_2 size.

   This rule has far reaching implications in quantum biology and neuroscience since macroscopic quantum phases become possible as the basic criterion stating that macroscopic quantum phase becomes possible if the density of particles is so high that particles as Compton length sized objects overlap. Dark matter therefore forms macroscopic quantum phases. One implication is the explanation of mysterious looking quantal effects of ELF radiation in EEG frequency range on vertebrate brain: $E = hf$ implies that the energies for the ordinary value of Planck constant are much below the thermal threshold but large value of Planck constant changes the situation. Also the phase transitions modifying the value of Planck constant and changing the lengths of flux tubes (by quantum classical correspondence) are crucial as also reconnections of the flux tubes.

The hierarchy of Planck constants suggests also a

new interpretation for FQHE (see `http://tinyurl.com/y89xp4bu`) (fractional quantum Hall effect) [K22] in terms of anyonic phases with non-standard value of effective Planck constant realized in terms of the effective multi-sheeted covering of embedding space: multi-sheeted space-time is to be distinguished from many-sheeted space-time.

3. In astrophysics and cosmology the implications are even more dramatic if one believes that also $\hbar_{gr}$ corresponds to effective Planck constant interpreted as number of sheets of multi-furcation. It was Nottale (see `http://tinyurl.com/ya6f3s4l`) [E15] who first introduced the notion of gravitational Planck constant as $\hbar_{gr} = GMm/v_0$, $v_0 < 1$ has interpretation as velocity light parameter in units $c = 1$. This would be true for $GMm/v_0 \geq 1$. The interpretation of $\hbar_{gr}$ in TGD framework is as an effective Planck constant associated with space-time sheets mediating gravitational interaction between masses M and m. The huge value of $\hbar_{gr}$ means that the integer $\hbar_{gr}/\hbar_0$ interpreted as the number of sheets of covering is gigantic and that Universe possesses gravitational quantum coherence in super-astronomical scales for masses which are large. This would suggest that gravitational radiation is emitted as dark gravitons which decay to pulses of ordinary gravitons replacing continuous flow of gravitational radiation.

   It must be however emphasized that the interpretation of $\hbar_{gr}$ could be different, and it will be found that one can develop an argument demonstrating how $\hbar_{gr}$ with a correct order of magnitude emerges from the effective space-time metric defined by the anti-commutators appearing in the Kähler-Dirac equation.

4. Why Nature would like to have large effective value of Planck constant? A possible answer relies on the observation that in perturbation theory the expansion takes in powers of gauge couplings strengths $\alpha = g^2/4\pi\hbar$. If the effective value of $\hbar$ replaces its real value as one might expect to happen for multi-sheeted particles behaving like single particle, α is scaled down and perturbative expansion converges for the new particles. One could say that Mother Nature loves theoreticians and comes in rescue in their attempts to calculate. In quantum gravitation the problem is especially acute since the dimensionless parameter $GMm/\hbar$ has gigantic value. Replacing $\hbar$ with $\hbar_{gr} = GMm/v_0$ the coupling strength becomes $v_0 < 1$.

2.2 Space-Time Correlates For The Hierarchy Of Planck Constants

The hierarchy of Planck constants was introduced to TGD originally as an additional postulate and formulated as the existence of a hierarchy of embedding spaces defined as Cartesian products of singular coverings of M^4 and CP_2 with numbers of sheets given by integers n_a and n_b and $\hbar = n\hbar_0$. $n = n_a n_b$.

With the advent of zero energy ontology, it became clear that the notion of singular covering space of the embedding space could be only a convenient auxiliary notion. Singular means that the sheets fuse together at the boundary of multi-sheeted region. The effective covering space emerges naturally from the vacuum degeneracy of Kähler action meaning that all deformations of canonically imbedded M^4 in $M^4 \times CP_2$ have vanishing action up to fourth order in small perturbation. This is clear from the fact that the induced Kähler form is quadratic in the gradients of CP_2 coordinates and Kähler action is essentially Maxwell action for the induced Kähler form. The vacuum degeneracy implies that the correspondence between canonical momentum currents $\partial L_K/\partial(\partial_\alpha h^k)$ defining the Kähler-Dirac gamma matrices [K12] and gradients $\partial_\alpha h^k$ is not one-to-one. Same canonical momentum current corresponds to several values of gradients of embedding space coordinates. At the partonic 2-surfaces at the light-like boundaries of CD carrying the elementary particle quantum numbers this implies that the two normal derivatives of h^k are many-valued functions of canonical momentum currents in normal directions.

Multi-furcation is in question and multi-furcations are indeed generic in highly non-linear systems and Kähler action is an extreme example about non-linear system (see **Fig.** `http://tgdtheory.fi/appfigures/planckhierarchy.jpg`, or **Fig. ??** in the appendix of this book). What multi-furcation means in quantum theory? The branches of multi-furcation are obviously analogous to single particle states. In quantum theory second quantization means that one constructs not only single particle states but also the many particle states formed from them. At space-time level single particle states would correspond to N branches b_i of multi-furcation carrying fermion number. Two-particle states would correspond to 2-fold covering consisting of 2 branches b_i and b_j of multi-furcation. $N-$particle state would correspond to N-sheeted covering with all branches present and carrying elementary particle quantum numbers. The branches coincide at the partonic 2-surface but since their normal space data are different they correspond to different tensor product factors of state space. Also now the factorization $N = n_a n_b$ occurs but now n_a and n_b would relate to branching in the direction of space-like 3-surface and light-like 3-surface rather than M^4 and CP_2 as in the original hypothesis.

In light of this the working hypothesis adopted during last years has been too limited: for some reason I ended up to propose that only N-sheeted covering corresponding to a situation in which all N branches are present is possible. Before that I quite correctly considered more general option based on intuition that one has many-particle states in the multi-sheeted space. The erratic form of the working hypothesis has not been used in applications.

Multi-furcations relate closely to the quantum criticality of Kähler action. Feigenbaum bifurcations (see `http://tinyurl.com/2swb2p`) represent a toy example of a system which via successive bifurcations approaches chaos. Now more general multi-furcations in which each branch of given multi-furcation can multi-furcate further, are possible unless on poses any additional conditions. This allows to identify additional aspect of the geometric arrow of time. Either the positive or negative energy part of the zero energy state is "prepared" meaning that single n-sub-furcations of N-furcation is selected. The most general state of this kind involves superposition of various n-sub-furcations.

2.3 Basic Phenomenological Rules Of Thumb In The New Framework

It is important to check whether or not the refreshed view about dark matter is consistent with existent rules of thumb.

1. The interpretation of quantized multi-furcations as WCW anyons explains also why the effective hierarchy of Planck constants defines a hierarchy of phases which are dark relative to each other. This is trivially true since the phases with different number of branches in multi-furcation correspond to disjoint regions of WCW so that the particles with different effective value of Planck constant cannot appear in the same vertex.

2. The phase transitions changing the value of Planck constant are just the multi-furcations and can be induced by changing the values of the external parameters controlling the properties of preferred extremals. Situation is very much the same as in any non-linear system.

3. In the case of massless particles the scaling of wavelength in the effective scaling of $\hbar$ can be understood if dark n-photons consist of n photons with energy E/n and wavelength $n\lambda$.

4. For massive particle it has been assumed that masses for particles and they dark counterparts are same and Compton wavelength is scaled up. In the new picture this need not be true. Rather, it would seem that wave length are same as for ordinary electron.

   On the other hand, p-adic thermodynamics predicts that massive elementary particles are massless most of the time. ZEO predicts that even virtual wormhole throats are massless. Could this mean that the picture applying on massless particle should apply to them at least at relativistic limit at which mass is negligible. This might be the case for bosons but for fermions also fermion number should be fractionalized and this is not possible in the recent picture. If one assumes that the n-electron has same mass as electron, the mass for dark single electron state would be scaled down by $1/n$. This does not look sensible unless the p-adic length defined by prime is scaled down by this fact in good approximation.

This suggests that for fermions the basic scaling rule does not hold true for Compton length $\lambda_c = \hbar_m$. Could it however hold for de-Broglie lengths $\lambda = \hbar/p$ defined in terms of 3-momentum? The basic overlap rule for the formation of macroscopic quantum states is indeed formulated for de Broglie wave length. One could argue that an $1/N$-fold reduction of density that takes place in the de-localization of the single particle states to the N branches of the cover, implies that the volume per particle increases by a factor N and single particle wave function is de-localized in a larger region of 3-space. If the particles reside at effectively one-dimensional 3-surfaces - say magnetic flux tubes - this would increase their de Broglie wave length in the direction of the flux tube and also the length of the flux tube. This seems to be enough for various applications.

One important notion in TGD inspired quantum biology is dark cyclotron state.

1. The scaling $\hbar \rightarrow k\hbar$ in the formula $E_n = (n+1/2)\hbar eB/m$ implies that cyclotron energies are scaled up for dark cyclotron states. What this means microscopically has not been obvious but the recent picture gives a rather clearcut answer. One would have k-particle state formed from cyclotron states in N-fold branched cover of space-time surface. Each branch would carry magnetic field B and ion or electron. This would give a total cyclotron energy equal to kE_n. These cyclotron states would be excited by k-photons with total energy $E = khf$ and for large enough value of k the energies involved would be above thermal threshold. In the case of Ca^{++} one has $f = 15$ Hz in the field $B_{end} = .2$ Gauss. This means that the value of $\hbar$ is at least the ratio of thermal energy at room temperature to $E = hf$. The thermal frequency is of order 10^{12} Hz so that one would have $k \simeq 10^{11}$. The number branches would be therefore rather high.

2. It seems that this kinds of states which I have called cyclotron Bose-Einstein condensates could make sense also for fermions. The dark photons involved would be Bose-Einstein condensates of k photons and wall of them would be simultaneously absorbed. The biological meaning of this would be that a simultaneous excitation of large number of atoms or molecules can take place if they are localized at the branches of N-furcation. This would make possible coherent macroscopic changes. Note that also Cooper pairs of electrons could be $n = 2$-particle states associated with N-furcation.

There are experimental findings suggesting that photosynthesis involves de-localized excitations of electrons and it is interesting so see whether this could be understood in this framework.

1. The TGD based model relies on the assumption that cyclotron states are involved and that dark photons with the energy of visible photons but with much longer wavelength are involved. Single electron excitations (or single particle excitations of Cooper pairs) would generate negentropic entanglement automatically.

2. If cyclotron excitations are the primary ones, it would seem that they could be induced by dark N-photons exciting all N electrons simultaneously. N-photon should have energy of a visible photon. The number of cyclotron excited electrons should be rather large if the total excitation energy is to be above thermal threshold. In this case one could not speak about cyclotron excitation however. This would require that solar photons are transformed to n-photons in N-furcation in biosphere.

3. Second - more realistic looking - possibility is that the incoming photons have energy of visible photon and are therefore $n = 1$ dark photons de-localized to the branches of the N-furcation. They would induce de-localized single electron excitation in WCW rather than 3-space.

2.4 Charge Fractionization And Anyons

It is easy to see how the effective value of Planck constant as an integer multiple of its standard value emerges for multi-sheeted states in second quantization. At the level of Kähler action one can assume that in the first approximation the value of Kähler action for each branch is same so that the total Kähler action is multiplied by n. This corresponds effectively to the scaling $\alpha_K \rightarrow \alpha_K/n$ induced by the scaling $\hbar_0 \rightarrow n\hbar_0$.

Also effective charge fractionization and anyons emerge naturally in this framework.

1. In the ordinary charge fractionization (see `http://tinyurl.com/26tmhoe`) the wave function decomposes into sharply localized pieces around different points of 3-space carrying fractional charges summing up to integer charge. Now the same happens at at the level of WCW ("world of classical worlds") rather than 3-space meaning that wave functions in E^3 are replaced with wave functions in the space-time of 3-surfaces (4-surfaces by holography implied by General Coordinate Invariance) replacing point-like particles. Single particle wave function in WCW is a sum of N sharply localized contributions: localization takes place around one particular branch of the multi-sheeted space time surface. Each branch carries a fractional charge q/N for teh analogs of plane waves.

   Therefore all quantum numbers are additive and fractionization is only effective and observable in a localization of wave function to single branch occurring with probability $p = 1/N$ from which one can deduce that charge is q/N.

2. The is consistent with the proposed interpretation of dark photons/gravitons since they could carry large spin and this kind of situation could decay to bunches of ordinary photons/gravitons. It is also consistent with electromagnetic charge fractionization and fractionization of spin.

3. The original - and it seems wrong - argument suggested what might be interpreted as a genuine fractionization for orbital angular momentum and also of color quantum numbers, which are analogous to orbital angular momentum in TGD framework. The observation was that a rotation through 2π at space-time level moving the point along space-time surface leads to a new branch of multi-furcation and $N+1$: th branch corresponds to the original one. This suggests that angular momentum fractionization should take place for M^4 angle coordinate ϕ because for it 2π rotation could lead to a different sheet of the effective covering.

   The orbital angular momentum eigenstates would correspond to waves $exp(i\phi m/N)$, $m = 0, 2, ..., N-1$ and the maximum orbital angular momentum would correspond the sum $\sum_{m=0}^{N-1} m/N = (N-1)/2$. The sum of spin and orbital angular momentum be therefore fractional.

   The different prediction is due to the fact that rotations are now interpreted as flows rotating the points of 3-surface along 3-surface rather than rotations of the entire partonic surface in embedding space. In the latter interpretation the rotation by 2π does nothing for the 3-surface. Hence fractionization for the total charge of the single particle states does not take place unless one adopts the flow interpretation. This view about fractionization however leads to problems with fractionization of electromagnetic charge and spin for which there is evidence from fractional quantum Hall effect.

2.5 What About The Relationship Of Gravitational Planck Constant To Ordinary Planck Constant?

Gravitational Planck constant is given by the expression $\hbar_{gr} = GMm/v_0$, where $v_0 < 1$ has interpretation as velocity parameter in the units $c = 1$. Can one interpret also $\hbar_{gr}$ as effective value of Planck constant so that its values would correspond to multi-furcation with a gigantic number of sheets. This does not look reasonable.

Could one imagine any other interpretation for $\hbar_{gr}$? Could the two Planck constants correspond to inertial and gravitational dichotomy for four-momenta making sense also for angular momentum identified as a four-vector? Could gravitational angular momentum and the momentum associated with the flux tubes mediating gravitational interaction be quantized in units of $\hbar_{gr}$ naturally?

1. Gravitational four-momentum can be defined as a projection of the M^4-four-momentum to space-time surface. It's length can be naturally defined by the effective metric $g_{eff}^{\alpha\beta}$ defined by the anti-commutators of the modified gamma matrices. Gravitational four-momentum

appears as a measurement interaction term in the Kähler-Dirac action and can be restricted to the space-like boundaries of the space-time surface at the ends of CD and to the light-like orbits of the wormhole throats and which induced 4- metric is effectively 3-dimensional.

2. At the string world sheets and partonic 2-surfaces the effective metric degenerates to 2-D one. At the ends of braid strands representing their intersection, the metric is effectively 4-D. Just for definiteness assume that the effective metric is proportional to the M^4 metric or rather - to its M^2 projection: $g^{kl}_{eff} = K^2 m^{kl}$.

   One can express the length squared for momentum at the flux tubes mediating the gravitational interaction between massive objects with masses M and m as

$$g^{\alpha\beta}_{eff} p_\alpha p_\beta = g^{\alpha\beta}_{eff} \partial_\alpha h^k \partial_\beta h^l p_k p_l \equiv g^{kl}_{eff} p_k p_l = n^2 \frac{\hbar^2}{L^2} \quad . \tag{2.1}$$

   Here L would correspond to the length of the flux tube mediating gravitational interaction and p_k would be the momentum flowing in that flux tube. $g^{kl}_{eff} = K^2 m^{kl}$ would give

$$p^2 = \frac{n^2 \hbar^2}{K^2 L^2} \quad .$$

   $\hbar_{gr}$ could be identifed in this simplified situation as $\hbar_{gr} = \hbar/K$.

3. Nottale's proposal requires $K = GMm/v_0$ for the space-time sheets mediating gravitational interacting between massive objects with masses M and m. This gives the estimate

$$p_{gr} = \frac{GMm}{v_0} \frac{1}{L} \quad . \tag{2.2}$$

   For $v_0 = 1$ this is of the same order of magnitude as the exchanged momentum if gravitational potential gives estimate for its magnitude. v_0 is of same order of magnitude as the rotation velocity of planet around Sun so that the reduction of v_0 to $v_0 \simeq 2^{-11}$ in the case of inner planets does not mean that the propagation velocity of gravitons is reduced.

4. Nottale's formula requires that the order of magnitude for the components of the energy momentum tensor at the ends of braid strands at partonic 2-surface should have value GMm/v_0. Einstein's equations $T = \kappa G + \Lambda g$ give a further constraint. For the vacuum solutions of Einstein's equations with a vanishing cosmological constant the value of h_{gr} approaches infinity. At the flux tubes mediating gravitational interaction one expects T to be proportional to the factor GMm simply because they mediate the gravitational interaction.

5. One can consider similar equation for gravitational angular momentum:

$$g^{\alpha\beta}_{eff} L_\alpha L_\beta = g^{kl}_{eff} L_k L_l = l(l+1)\hbar^2 \quad . \tag{2.3}$$

   This would give under the same simplifying assumptions

$$L^2 = l(l+1) \frac{\hbar^2}{K^2} \quad . \tag{2.4}$$

   This would justify the Bohr quantization rule for the angular momentum used in the Bohr quantization of planetary orbits.

Maybe the proposed connection might make sense in some more refined formulation. In particular the proportionality between $m^{kl}_{eff} = K m^{kl}$ could make sense as a quantum average. Also the fact, that the constant v_0 varies, could be understood from the dynamical character of m^{kl}_{eff}.

3 General Quantum Vision About Formation Of Structures

The basic observation is that in the case of a straight cosmic string creating a gravitational potential of form v_1^2/ρ Bohr quantization does not pose any conditions on the radii of the circular orbits so that a continuous mass distribution is possible.

This situation is obviously exceptional. If one however accepts the TGD based vision [K24] that the very early cosmology was cosmic string dominated and that elementary particles were generated in the decay of cosmic strings, this situation might have prevailed at very early times. If so, the differentiation of a continuous density of ordinary matter to form the observed astrophysical structures would correspond to an approach to a stationary situation governed by Bohr rules and in the first approximation one could neglect the intermediate stages.

Cosmic string need not be infinitely long: it could branch into flux tubes or flux sheets carrying the return flux. For large distances the whole structure would behave as a single mass point creating ordinary Newtonian gravitational potential. Also phase transitions in which the system emits magnetic flux tubes so that the contribution of the cosmic string to the gravitational force is reduced, are possible.

What is of utmost importance is that the cosmic string induces a breaking of the rotational symmetry selecting a unique preferred orbital plane in which gravitational acceleration is parallel to the plane. This is just what is observed in astrophysical systems and not easily explained in the Newtonian picture. In TGD framework this relates directly to the choice of quantization axis of angular momentum at the level of dark matter. This mechanism could be behind the formation of planar systems in all length scales including planets and their moons, planetary systems, galaxies, galaxy clusters in the scale of Mly, and even the concentration of matter at the walls of large voids in the scale of 100 Mly.

3.1 Simple Quantitative Model

The following elementary model allows to see how the addition of central mass forces the matter to quantized Bohr orbits via the formation of dark matter rings.

3.1.1 The equation for gravitational acceleration

The elementary model for circular orbits involves two equations: the identification radial kinetic acceleration with the acceleration due to the gravitational force and the condition stating quantization of the angular momentum, which requires some additional thought when cosmic string has infinite length.

In cylindrical coordinates the gravitational acceleration due to cosmic string is given by

$$\begin{aligned} a &= \frac{v_1^2}{\rho} \ , \\ v_1^2 &= G\frac{dM}{dL} \ . \end{aligned} \tag{3.1}$$

Here v_1 is the rotational velocity of the matter around cosmic string neglecting its own gravitational effects.

The condition for the radial acceleration gives

$$u = \frac{1}{\rho} = \frac{v^2 - v_1^2}{GM} \ . \tag{3.2}$$

3.1.2 Quantization of angular momentum

The condition for the quantization of angular momentum is not quite obvious since taking into account the mass of entire cosmic string would give an infinite Planck constant. The resolution of the problem relies on the effective 2-dimensionality and Z_n symmetry of the dark matter for $F-C$ option meaning that it forms rings.

Consider first the situation when only cosmic is present. For dark matter rings it is angular momentum per unit length which is quantized so that Planck constant is replaced with Planck constant per unit length. Hence one has

$$\frac{d\hbar}{dl} = G \times \frac{m}{2\pi} \times \frac{dM}{dL} \times \frac{1}{v_0} = \frac{m}{2\pi} \times \frac{v_1^2}{v_0} \ . \tag{3.3}$$

where m is the mass of dark matter ring. The inclusion of 2π is necessary in order to obtain internal consistency.

The quantization condition for the circular orbits in the presence of only cosmic string would read as

$$\frac{dm}{dl} \times v\rho = n \times \frac{d\hbar}{dl} = n \times \frac{m}{2\pi} \times \frac{v_1^2}{v_0} \ . \tag{3.4}$$

By using $dm/dl = m/2\pi\rho$, one obtains

$$v = n\frac{v_1^2}{v_0} \ . \tag{3.5}$$

Only $n = 1$ is consistent with $v = v_1^2/v_0$ resulting from the condition for the radial acceleration and there is no condition on ρ.

The contribution of the cosmic string to the Planck constant can be identified as

$$\hbar(string) = m \times \frac{v_1^2}{v_0}\rho \ . \tag{3.6}$$

One can say that a length ρ of cosmic string contributes to the Planck constant, and that the active part of that cosmic string and point on ring define an equilateral triangle with sides 1 and $\sqrt{5}$ so that Golden Mean emerges.

The generalization of this equation to the case when also central mass is present reads as

$$v\rho = n\frac{GM + \frac{v_1^2}{v_0}\rho}{v_0} \ . \tag{3.7}$$

This gives the quantization condition

$$u = \frac{vv_0 - nv_1^2}{nGM} \ . \tag{3.8}$$

3.1.3 Combination of the conditions

The two equations for $u = 1/\rho$ fix the spectrum of velocities and orbital radii. By introducing the parameter $v_1/v_0 = \epsilon$ and the variable $x = v/v_0$ one can write the basic equation as

$$x^2 - \frac{x}{n} = 0 \ . \tag{3.9}$$

The solutions are $x = 0$ and $x = 1/n$. Only the latter solution corresponds to $u > 0$. The same spectrum $v = v_0/n$ of velocities is obtained as in the case of hydrogen atom model so that only the radii are modified. The universality of the velocity spectrum corresponds to the reduction of the quantization of angular momentum to that of circulation implied by the Equivalence Principle.

The radii of the orbits are given by

$$\rho(n) = \frac{n^2}{1-n^2\epsilon^2} \times r_0 \ ,$$
$$r_0 = \frac{GM}{v_0^2} \ . \qquad (3.10)$$

For small values of n one obtains Bohr orbits for hydrogen atom like model. For $n = 1$ there is an upwards scaling of Bohr radius by $1/(1-\epsilon^2)$. For large values of n the distances between sub-sequent radii begin to rapidly increase and at the limit $n \rightarrow 1/\epsilon$ the radius becomes infinite. Hence only $n < 1/\epsilon$ orbits are possible meaning that the system has necessarily a finite size for a given value of v_0. Several values of v_0 are however suggested by the Bohr orbit model for the solar system.

3.2 Formation Of Ring Like Structures

One can consider an initial situation in which one has a continuous mass density rotating with a constant velocity around cosmic string defining the rotation axis of the planet. The situation is inherently unstable and a small perturbation forces the accumulation of both dark and visible matter to Bohr orbits and the upper bound for the value of n implies finite size of the system proportional to the central mass.

3.2.1 Rings of Saturn and Jupiter

The rings of Saturn and Jupiter [E8, E7] could be seen a intermediate states in the process leading to the formation of satellites. Both planets indeed possess a large number of satellites [E8, E7]. This would suggest that Saturn and Jupiter and outer planets in general are younger than the 4 inner planets in accordance with the different values of v_0. The orbital radii for lowest satellites correspond to $v_0 \rightarrow 16/15 v_0$, and $n = 5$ for Saturn and $v_0 \rightarrow 2v_0$ and $n = 5$ for Jupiter from the requirement that the two lowest satellites correspond in a reasonable approximation to the two lowest Bohr orbits. The radii of satellites do not directly correspond to the radii for Bohr orbits. Also the formation of inner and outer satellite systems differing by a fractal scaling from each other can be considered. Same mechanism would be at work in all length scales and the recently observed dark matter ring associated with a galactic cluster could result by a similar mechanism [E19].

The hierarchy of dark matters continues to elementary particle level and the differentiation by Bohr rules continues down to these levels. In particular, the formation of clumps of matter in Saturn rings [E9] could be seen as a particular instance of this process.

3.2.2 NASA Hubble Space Telescope Detects Ring of Dark Matter

The following announcement caught my attention during my morning webwalk.

NASA will hold a media teleconference at 1 p.m. EDT on May 15 to discuss the strongest evidence to date that dark matter exists. This evidence was found in a ghostly ring of dark matter in the cluster CL0024+17, discovered using NASA's Hubble Space Telescope. The ring is the first cluster to show a dark matter distribution that differs from the distribution of both the galaxies and the hot gas. The discovery will be featured in the May 15 issue of the Astrophysical Journal.

"Rings" puts bells ringing! Recall that in TGD Universe dark matter characterized by a gigantic value of constant [K16] making dark matter a macroscopic quantum phase in astrophysical length and time scales. In the model of planetary orbits the rings of dark matter around Bohr orbits force the visible matter at Bohr orbits. Rings- and also shell like structures - connected by radial flux tubes to central anyonic surface are expected in all length scales, even that for galaxy clusters and large voids.

Recall that the number theoretic hypothesis for the preferred values of Planck constants states that the gravitational Planck constant

$$\hbar = \frac{GMm}{v_0}$$

equals to a ruler-and-compass rational which is ratio $q = n_1/n_2$ of ruler-and-compass integers n_i expressible as a product of form $n = 2^k \prod F_s$, where all Fermat primes F_s are different. Only four of them are known and they are given by 3, 5, 17, 257, $2^{16}+1$. $v_0 = 2^{-11}$ applies to inner planets and $v_0 = 2^{-11}/5$ to outer planets and the conditions from the quantization of $\hbar$ are satisfied.

The obvious TGD inspired hypothesis is that the dark matter ring corresponds to Bohr orbit. If so, the radius of the ring is given by

$$r_n = n^2 r_0 \ ,$$

where r_0 is Bohr radius and n is integer. The Bohr radius is given

$$r_0 = \frac{GM}{v_0^2} \ ,$$

where one has $1/v_0 = k \times 2^{11}$, k a small integer with preferred value $k = 1$. M is the total mass in the dense core region inside the ring. This would give a radius of about 2000 times Schwartschild radius for the lowest orbit.

This prediction can be confronted with the data [E19] .

1. From the "*Summary and Conclusions* " of the article the radius of the ring is about.4 Mpc, which makes in a good approximation r=1.2 Mly. The ring corresponds actually to a bump in the interval 60"-85" centered at 75" (figure 10 of [E19] gives idea about the bump). The mass in the dense core within radius which is almost half of the ring radius is about $M = 1.5 \times 10^{14} \times M_{Sun}$. The mass estimate based on gravitational lensing gives $M = 1.8 \times 10^{14} \times M_{Sun}$. If the gravitational lensing involves dark mass not in the central core, the first value can be used as the estimate. The Bohr radius this system is therefore

$$r_0 = 1.5 \times 10^{14} \times r_0(Sun) \ ,$$

where I have assumed $v_0 = 2^{-11}$ as for the inner planets in the model for the solar system.

2. The Bohr orbit for our planetary system predicts correctly Mercury's orbital radius as n=3 Bohr orbit for $v_0 = 2^{-11}$ so that one has

$$r_0(Sun) = \frac{r_M}{9} \ ,$$

where r_M is Mercury's orbital radius. This gives

$$r_0 = 1.5 \times 10^{14} \times \frac{r_M}{9} \ .$$

Mercury's orbital radius is in a good approximation $r_M = .4$ AU =.016 ly. This gives $r_0 = 11$ Mly to be compared with $r_0 = 1$ 1.2 Mly deduced from the observations. The result is 9 times too large.

3. If one replaces v_0 with $3v_0$ one obtains downwards scaling by a factor of 1/9, which gives $r_0 = 1.2$ Mly which can be found from the Summary and Conclusions of [E19]. The general hypothesis indeed allows to scale v_0 by a factor 3.

4. If one considers instead of Bohr orbits genuine solutions of Schrödinger equation then only $n > 1$ structures can correspond to rings like structures. Minimal option would be $n = 2$ with v_0 replaced with $6v_0$.

The conclusion would be that the ring could correspond to the lowest possible Bohr orbit for $v_0 = 3\times 2^{-11}$. I would have been really happy if the favored value of v_0 had appeared in the formula but the consistency with the ruler-and-compass hypothesis serves as a consolation. Skeptic can of course always argue that this is a pure accident. If so, it would be an addition to long series of accidents (planetary radii in solar system and radii of exoplanets). One can of course search rings at radii corresponding to $n = 2, 3, ...$

3.3 A Quantum Model For The Dark Part Of The Central Mass And Rings

It is interesting to look for a simple quantum model for the dark part of the central mass and possibly also of rings. As a first approximation one can consider a cylindrically symmetric pancake of height L and radius R. Approximate spherical symmetry suggest $L = 2R$.

The governing conditions are

$$\begin{aligned} v^2(\rho) &= G(dM/dl)(\rho) + v_1^2 \ , \\ v(\rho) &= \frac{v_0}{n} \ . \end{aligned} \tag{3.11}$$

Previous considerations suggest that the v_1^2 term from the cosmic string can be neglected. The general prediction is that the system has finite size and mass irrespective of the form of the distribution.

3.3.1 Four options

One can consider four kinds of mass distributions.

1. The scaling law $(dM/dl)(\rho) \propto K(\rho/\rho_0)^k$, $k \geq 0$, implies

$$\begin{aligned} v(\rho) &= \sqrt{GK}(\rho/\rho_0)^{k/2} \ , \\ \omega(\rho) &= \sqrt{GK}(\rho/\rho_0)^{k/2-1} \ , \\ \rho(n) &= \rho_0(v_0/\sqrt{GK})^{2/k} \times n^{-2/k} \ . \end{aligned} \tag{3.12}$$

   The radii decrease as $n^{-2/k}$ and largest radius is $\rho_0(v_0^2/GK)$. For constant mass density one obtains $k = 2$, rigid body rotation, and $\rho = \rho_0/n$ so that kind of reverted harmony of spheres would result. Quite generally, $v(\rho)$ is a non-decreasing function of ρ from the first condition. This reflects the 2-dimensionality of the situation.

2. If the mass distribution is logarithmic $M(\rho) = Klog^2(\rho/\rho_0)$ one has $v = \sqrt{GK}log(\rho/\rho_0)$ and $\rho(n) = \rho_0 exp(k/n)$, $k = v_0/\sqrt{GK}$. One obtains what might be regarded as a cylindrical shell $\rho/\rho_0 \in [1, e^k]$ and with density $dM/dl \propto 2log(\rho)/\rho$. This kind of distribution could work in the case of planetary rings if the tidal effects of the central mass can be neglected.

3. p-Adic length scale hypothesis suggest the distribution $\rho(n) = 2^{-k}\rho_0$ for the radii of the "mass shells". This would give $v(\rho) = v_0/|log_2(\rho/\rho_0)|$ and

$$(dM/dl)(\rho) = \frac{v_0^2}{G|log_2(\rho/\rho_0)|^2} = \frac{M}{r_0|log_2(\rho/\rho_0)|^2} \ .$$

   Note that the most general form of p-adic length scale hypothesis allows $\rho(n) = 2^{-k/2}\rho_0$ This option defines the only working alternative for the dark central mass. Note that this would explain Titius-Bode law [E10] if planets have formed around dark matter shells or rings which have formed part of Sun during primordial stage.

4. The distribution of radii of form $\rho(n)/\rho_0 = x - n$ might serve as a model for planetary rings if the tidal effects of the central mass can be neglected. In this case one as

$$(dM/dl)(\rho) = \frac{M}{r_0(x - \frac{\rho}{\rho_0})^2} \ .$$

   The radius R must satisfy $R < x\rho_0$. The masses of the annuli must increase with ρ.

3.3.2 Only the p-adic variant works as a model for central mass

It is interesting to look what the three variants of the model would predict for the radius of Earth. If the pancake has height $2R$, the relationship between radius and total mass can be expressed as $M = 2\pi(dM/dl)R^3$. Using $M_E = 3 \times 10^{-6} M_{Sun}$, and $r_0(Sun) \simeq R_M/9$, where $r_M = 5.8 \times 10^4$ Mm is the orbital radius of Mercury, one obtains by scaling $r_0 = GM_E/v_0^2 \simeq 20$ km for $v_0 = 2^{-11}$.

1. The options 1) and 2) fail. Constant density would give $R = 140$ km, which is about 2 per cent of the actual radius $R_E = 6.372797$ Mm and 10 percent about the radius 1.2 Mm of the inner core. The "inner inner core" of Earth happens to have radius of 300 km. For the logarithmic mass distribution one would obtain $R = r_0/2 \simeq 10$ km.
2. The option 3) inspired by the p-adic length scale hypothesis works and predicts $k^2|log_2(R/\rho_0)|^2 = 2R/r_0$. $\rho_0 = 2R$ gives $k \simeq 25$. This alternative works also in the more general case since one can make the radius arbitrarily large by a proper choice of the integer k. The universal prediction would be that dark matter appears as shells corresponding to decreasing p-adic length scales coming as powers $p \simeq 2^k$. The situation would be very much analogous to that in atomic physics. The prediction conforms with the many-sheeted generalization of the model for the asymptotic state of the star for which the matter is concentrated on a thin cell [K29]. The model brings in mind also the large voids of size about 100 Mly.
3. The suspiciously small value of r_0 forces to ask whether the value of v_0 for Earth should be much smaller than $v_0 = 2^{-11}$. Also the radius of Moon's orbit would require $n \sim 138$ for this value to be compared with $n \geq 5$ for the moons of Saturn and Jupiter. If the age of Earth is much longer than that of outer planets, one would expect that more phase transitions reducing v_0 forced by the cosmic expansion in average sense have taken place. $v_0 \rightarrow v_0/20$ would give $r_0 \simeq 8$ Mm to be compared with $R_E = 6.4$ Mm. Moon's orbit would correspond to $n = 7$ in a reasonable approximation. This choice of v_0 would allow $k = 1$.

The small value of v_0 might be understood from the fact that inner planets are older than outer ones so that the cosmic expansion in the average sense has forced larger number of phase transitions reducing the value of v_0 inducing a fractal scaling of the system. Ruler-and-compass hypothesis [K23] suggests preferred values of cosmic times for the occurrence of these transitions. Without this hypothesis the phase transitions could form almost continuum. For this option the failure of options 1) and 2) is even worse.

3.4 Two Stellar Components In The Halo Of Milky Way

Bohr orbit model for astrophysical objects suggests that also galactic halo should have a modular structure analogous to that of planetary system or the rings of Saturn rather than that predicted by continuous mass distribution. Quite recently it was reported that the halo of Milky Way - earlier thought to consist of single component - seems to consist of two components [E17, E23]. Even more intriguingly, the stars in these halos rotate in opposite directions. The average velocities of rotation are about 25 km/s and 50 km/s for inner and outer halos respectively. The inner halo corresponds to a range 10-15 kpc of orbital radii and outer halo to 15-20 kpc. Already the constancy of rotational velocity is strange and its increase even stranger. The orbits in inner halo are more eccentric with axial ratio $r_{min}/r_{max} \simeq .6$. For outer halo the ratio varies in the range $.9 - 1.0$. The abundances of elements heavier than Lithium are about 3 times higher in the inner halo which suggests that it has been formed earlier.

Bohr orbit model would explain halos as being due to the concentration of visible matter around ring like structures of dark matter in macroscopic quantum state with gigantic gravitational Planck constant. This would explain also the opposite directions of rotation.

One can consider two alternative models predicting constant rotation velocity for circular orbits. The first model allows circular orbits with arbitrary plane of rotation, second model and the hybrid of these models only for the orbits in galactic plane.

1. The original model assumes that galactic matter has resulted in the decay of cosmic string like object so that the mass inside sphere of radius R is $M(R) \sim kR$.

2. In the second model the gravitational acceleration is due to gravitational field of a cosmic string like object transversal to the galactic plane. String creates no force parallel to string but $1/\rho$ radial acceleration orthogonal to the string. Of course, there is the gravitational force created by galactic matter itself. One can also associate cosmic string like objects with the circular halos themselves and it seems that this is needed in order to explain the latest findings.

The big difference in the average rotation velocities $\langle v_\phi \rangle$. or inner and outer halos cannot be understood solely in terms of the high eccentricity of the orbits in the inner halo tending to reduce $\langle v_\phi \rangle$. Using the conservation laws of angular momentum ($L = mv_{min}\rho_{max}$) and of energy in Newtonian approximation one has $\langle v_\phi \rangle = \rho_{max} v_{min} \langle\langle 1/\rho \rangle$. This gives the bounds

$$v_{min} < \langle v_\phi \rangle < v_{max} = v_{min}\frac{\rho_{max}}{\rho_{min}} \simeq 1.7 v_{min} \quad .$$

For both models $v = v_0 = \sqrt{k}$, $k = TG$, (T is the effective string tension) for circular orbits. Internal consistency would require $v_{min} < \langle v_\phi \rangle \simeq .5v_0 < v_{max} \simeq 1.7v_{min}$. On the other hand, $v_{max} > v_0$ and thus $v_{min} > .6v_0$ must hold true since the sign of radial acceleration for ρ_{min} is positive. $.5v_0 > v_{min} > .6v_0$ means a contradiction.

The big increase of the average rotation velocity suggests that inner and outer halos correspond to closed cosmic string like objects around which the visible matter has condensed. The inner string like object would create an additional gravitational field experienced by the stars of the outer halo. The increase of the effective string tension by factor x corresponds to the increase of $\langle v_\phi \rangle$ by a factor $\sqrt{x}$. The increase by a factor 2 plus higher eccentricity could explain the ratio of average velocities.

4 Quantum Chaos In Astrophysical Length Scales

The stimulus for writing this section came from the article "Quantum Chaos" by Martin Gurtzwiller [B7]. Occasionally it can happen that even this kind of a masterpiece of scientific writing manages to stimulate only an intention to read it more carefully later. When you indeed read it again years later it can shatter you into a wild resonance. Just this occurred at this time.

4.1 Brief Summary About Quantum Chaos

The article discusses of Gurtzwiller the complex regime between quantal and classical behavior as it was understood at the time of writing (1992). As a non-specialist I have no idea about possible new discoveries since then.

The article introduces the division of classical systems into regular (R) and chaotic (P in honor of Poincare) ones. Besides this one has quantal systems (Q). There are three transition regions between these three realms.

1. R-P corresponds to transition to classical chaos and KAM theorem is a powerful tool allowing to organize the view about P in terms of surviving periodic orbits.

2. Quantum-classical transition region R-Q corresponds to high quantum number limit and is governed by Bohr's correspondence principle. Highly excited hydrogen atom - Rydberg atom - defines a canonical example of the situation.

3. Somewhat surprisingly, it has turned out that also P-Q region can be understood in terms of periodic classical orbits (nothing else is available!). P-Q region can be achieved experimentally if one puts Rydberg atom in a strong magnetic field. At the weak field limit quantum states are de-localized but in chaotic regime the wave functions become strongly concentrated along a periodic classical orbits.

   At the level of dynamics the basic example about P-Q transition region discussed is the chaotic quantum scattering of electron in atomic lattice. Classical description does not work: a superposition of amplitudes for orbits, which consist of pieces which are fragments of a periodic orbit plus localization around atom is necessary.

The fractal wave function patterns associated with say hydrogen atom in strong magnetic field are extremely beautiful and far from chaotic. Even in the case of chaotic quantum scattering one has interference of quantum amplitudes for classical Bohr orbits and also now Fourier transform exhibits nice peaks corresponding to the periods of classical orbits. The term chaos seems to be an unfortunate choice referring to our limited cognitive capacities rather than the actual physical situation and the term quantum complexity would be more appropriate.

4. For a consciousness theorist the challenge is to try to formulate in a more precise manner this fact. Quantum measurement theory with a finite measurement resolution indeed provide the mathematics necessary for this purpose.

4.2 What Does The Transition To Quantum Chaos Mean?

The transition to quantum chaos in the sense the article discusses it means that a system with a large number of virtually independent degrees of freedom (in very general sense) makes a transition to a phase in there is a strong interaction between these degrees of freedom. Perturbative phase becomes non-perturbative. This means emergence of correlations and reduction of the effective dimension of the system to a finite fractal dimension. When correlations become complete and the system becomes a genuine quantum system, the dimension of the system is genuinely reduced and again non-fractal. In this sense one has transition via complexity to new kind of order.

4.2.1 The level of stationary states

At the level of energy spectrum this means that the energy of system which correspond to sums of virtually independent energies and thus is essentially random number becomes non-random. As a consequence, energy levels tend to avoid each other, order and simplicity emerge but at the collective level. Spectrum of zeros of Zeta has been found to simulate the spectrum for a chaotic system with strong correlations between energy levels. Zeta functions indeed play a key role in the proposed description of quantum criticality associated with the phase transition changing the value of Planck constant.

4.2.2 The importance of classical periodic orbits in chaotic scattering

Poincare with his immense physical and mathematical intuition foresaw that periodic classical orbits should have a key role also in the description of chaos. The study of complex systems indeed demonstrates that this is the case although the mathematics and physics behind this was not fully understood around 1992 and is probably not so even now. The basic discovery coming from numerical simulations is that the Fourier transform of a chaotic orbits exhibits peaks at frequencies which correspond to the periods of closed orbits. From my earlier encounters with quantum chaos I remember that there is quantization of periodic orbits so that their periods are proportional to $log(p)$, p prime in suitable units. This suggests a connection of arithmetic quantum field theory and with p-adic length scale hypothesis.

The chaotic scattering of electron in atomic lattice is discussed as a concrete example. In the chaotic situation the notion of electron consists of periods spend around some atom continued by a motion along along some classical periodic orbit. This does not however mean loss of quantum coherence in the transitions between these periods: a purely classical model gives non-sensible results in this kind of situation. Only if one sums scattering amplitudes over all piecewise classical orbits (not all paths as one would do in path integral quantization) one obtains a working model.

4.2.3 In what sense complex systems can be called chaotic?

Speaking about quantum chaos instead of quantum complexity does not seem appropriate to me unless one makes clear that it refers to the limitations of human cognition rather than to physics. If one believes in quantum approach to consciousness, these limitations should reduce to finite resolution of quantum measurement not taken into account in standard quantum measurement theory.

In the framework of hyper-finite factors of type II_1 finite quantum measurement resolution is described in terms of inclusions $\mathcal{N} \subset \mathcal{M}$ of the factors and sub-factor $\mathcal{N}$ defines what might be called $\mathcal{N}$-rays replacing complex rays of state space. The space $\mathcal{M}/\mathcal{N}$ has a fractal dimension characterized by quantum phase and increases as quantum phase $q = exp(i\pi/n)$, $n = 3, 4, ...$, approaches unity which means improving measurement resolution since the size of the factor $\mathcal{N}$is reduced.

Fuzzy logic based on quantum qbits applies in the situation since the components of quantum spinor do not commute. At the limit $n \to \infty$ one obtains commutativity, ordinary logic, and maximal dimension. The smaller the n the stronger the correlations and the smaller the fractal dimension. In this case the measurement resolution makes the system effectively strongly correlated as n approaches its minimal value $n = 3$ for which fractal dimension equals to 1 and Boolean logic degenerates to single valued totalitarian logic.

Non-commutativity is the most elegant description for the reduction of dimensions and brings in reduced fractal dimensions smaller than the actual dimension. Again the reduction has interpretation as something totally different from chaos: system becomes a single coherent whole with strong but not complete correlation between different degrees of freedom. The interpretation would be that in the transition to non-chaotic quantal behavior correlation becomes complete and the dimension of system again integer valued but smaller. This would correspond to the cases $n = 6$, $n = 4$, and $n = 3$ ($D = 3, 2, 1$).

4.3 Quantum Chaos In Astrophysical Scales?

The following considerations represent an updated form of the first sketch about how quantum chaos could emerge in astrophysical length scales.

4.3.1 Transition to quantum chaos as reduction of the symmetry groups G_a and G_b

Anyonic 2-surfaces formed by flux tubes around orbits of massive objects connected to the central nearly spherical anyonic 2-surfaces by radial flux tubes and characterized by a fixed value of v_0 is the first key element of the picture. Second key element is the general formula for Planck constant forcing to conclude that the sequential de-coherence reducing (n_a, n_b) gradually to $(n_a, n_b) = (1, 1)$ requires generation of sub-harmonics of the original graviton frequency in the situation when $r = \hbar/\hbar_0$ is genuine rational $r = m/n$.

The transition to chaos must always correspond to a reduction of the symmetries so that $(n_a, n_b) = (1, 1)$ phase is maximally chaotic. Only for $C - C$ option this process corresponds always to a reduction of Planck constant. There are two mechanisms of de-coherence: the first one is favored for the factor space option and second one for the covering space option.

1. Assuming conservation of energy and number of quanta in phase transitions (so that quanta leak between the pages of the Big Book) one has $E = \hbar\omega = \hbar_0\omega_0$ giving $\omega = \omega_0/r$, $r = \hbar/\hbar_0$. For $C - C$ *resp.* $F - C$ option this gives $\omega = \omega_0/(n_a n_b)$ *resp.* $\omega = \omega_0 \times (n_a/n_b)$. For $C-C$ option de-coherence process would mean a sequence of transitions in which frequencies steadily increase: this does not look plausible in the case of large $\hbar$ gravitons. For $F - C$, $C - F$ and $F - F$ options de-coherence can also reduce frequencies. If n_i are proportional to multiples of 2^k as ruler and compass hypothesis implies, period doubling regarded as a possible route to chaos is also involved but the number of period doublings is always finite. For classical orbits this would correspond to the emergence of small perturbations with n-fold period spoiling exact periodicity. Ruler-and-compass hypothesis implies very powerful predictions for the resulting frequency spectrum. This mechanism is natural for the reduction of n_i in the case of factor space option.

2. For the second mechanism frequencies are not affected so that energy conservation requires the decay of quantum to a bundle of quanta with a smaller value of Planck constant. The reduction factor for the energy is $R = r_f/r_i$ and the number of quanta is $N = r_i/r_f$ and integer if the reduction of Planck constant occurs only for the reduction of n_i for covering space option, which is thus favored.

4.3.2 Quantum criticality and chaos

1. TGD Universe is quantum critical. The most important implication of quantum criticality of TGD Universe is that it fixes the value of Kähler coupling strength, the only free parameter appearing in definition of the theory as the analog of critical temperature. The dark matter hierarchy characterized partially by the increasing values of Planck constant allows to characterize more precisely what quantum criticality might means. By quantum criticality space-time sheets are analogs of Bohr orbits. Since quantum criticality corresponds to P-Q region, the localization of wave functions around generalized Bohr orbits should occur quite generally in some scale.

2. Elementary particles are maximally quantum critical systems analogous to H_2O at tri-critical point and can be said to be in the intersection of embedding spaces labeled by various values of Planck constants. Planck constant does not characterize the elementary particle proper. Rather, each field body of particle (em, weak, color, gravitational) is characterized by its own Planck constant and this Planck constant characterizes interactions. The generalization of the notion of the embedding space allows to formulate this idea in precise manner and each sector of embedding space is characterized by discrete symmetry groups G_a and G_b acting in CD and CP_2 degrees of freedom either on covering or orbifold.

3. Dark matter hierarchy makes TGD Universe an ideal laboratory for studying P-Q transitions with chaos identified as quantum critical phase between two values of Planck constant with larger value of Planck constant defining the "quantum" phase and smaller value the "classical" phase. Dark matter is localized near Bohr orbits and is analogous to quantum states localized near the periodic classical orbits. Planetary Bohr orbitology provides a particularly interesting astrophysical application of quantum chaos.

4. The above described picture applies about chaotic quantum scattering applies quite generally in quantum TGD. Path integral is replaced with a functional integral over classical space-time evolutions and the failure of the complete classical non-determinism is analogous to the transition between classical orbits. Functional integral also reduces to perturbative functional integral around maxima of Kähler function.

4.3.3 Dark matter structures as generalization of periodic orbits

The matter with ordinary or smaller value of Planck constant can form bound states with these dark matter structures. The dark matter circles would be the counterparts for the periodic Bohr orbits dictating the behavior of the quantum chaotic system. Visible matter (and more generally, dark matter at the lower levels of hierarchy behaving quantally in shorter length and time scales) tends to stay around these periodic orbits and in the ideal case provides a perfect classical mimicry of quantum behavior. Dark matter structures would effectively serve as selectors of the closed orbits in the gravitational dynamics of visible matter.

As one approaches classicality the binding of the visible matter to dark matter gradually weakens. Mercury's orbit is not quite closed, planetary orbits become ellipses, comets have highly eccentric orbits or even non-closed orbits. For non-closed quantum description in terms of binding to dark matter does not makes sense at all.

The classical regular limit (R) would correspond to a decoupling between dark matter and visible matter. A motion along geodesic line is obtained but without Bohr quantization in gravitational sense since Bohr quantization using ordinary value of Planck constant implies negative energies for $GMm \geq 1$. The preferred extremal property of the space-time sheet could however still imply some quantization rules but these might apply in "vibrational" degrees of freedom.

4.3.4 Quantal chaos in gravitational scattering?

The chaotic motion of astrophysical object becomes the counterpart of quantum chaotic scattering. By Equivalence Principle the value of the mass of the object does not matter at all so that the motion of sufficiently light objects in solar system might be understandable only by assuming quantum chaos.

The orbit of a gravitationally unbound object such as comet could define the basic example. The rings of Saturn and Jupiter could represent interesting shorter length scale phenomena possible involving quantum scattering. One can imagine that the visible matter object spends some time around a given dark matter circle (binding to atom), makes a transition along a radial spoke to the next circle, and so on.

The prediction is that dark matter forms rings and cart-wheel like structures of astrophysical size. These could become visible in collisions of say galaxies when stars get so large energy as to become gravitationally unbound and in this quantum chaotic regime can flow along spokes to new Bohr orbits or to gravi-magnetic flux tubes orthogonal to the galactic plane. Hoag's object represents a beautiful example of a ring galaxy [E18]. Remarkably, there is direct evidence for galactic cart-wheels (for pictures of them see [E1]). There are also polar ring galaxies consisting of an ordinary galaxy plus ring approximately orthogonal to it and believed to form in galactic collisions [E6]. The ring rotating with the ordinary galaxy can be identified in terms of gravi-magnetic flux tube orthogonal to the galactic plane.

5 Gravitational Radiation And Large Value Of Gravitational Planck Constant

The description of gravitational radiation provides a stringent test for the idea about dark matter hierarchy with arbitrary large values of Planck constants. In accordance with quantum classical correspondence, one can take the consistency with classical formulas as a constraint allowing to deduce information about how dark gravitons interact with ordinary matter. In the following standard facts about gravitational radiation are discussed first and then TGD based view about the situation is sketched.

5.1 Standard View About Gravitational Radiation

5.1.1 Gravitational radiation and the sources of gravitational waves

Classically gravitational radiation corresponds to small deviations of the space-time metric from the empty Minkowski space metric [E2]. Gravitational radiation is characterized by polarization, frequency, and the amplitude of the radiation. At quantum mechanical level one speaks about gravitons characterized by spin and light-like four-momentum.

The amplitude of the gravitational radiation is proportional to the quadrupole moment of the emitting system, which excludes systems possessing rotational axis of symmetry as classical radiators. Planetary systems produce gravitational radiation at the harmonics of the rotational frequency. The formula for the power of gravitational radiation from a planetary system given by

$$P = \frac{dE}{dt} = \frac{32}{5}\frac{G^4M_1^2M_2^2(M_1+M_2)}{R^5} \ . \tag{5.1}$$

This formula can be taken as a convenient quantitative reference point.

Planetary systems are not very effective radiators. Because of their small radius and rotational asymmetry supernovas are much better candidates in this respect. Also binary stars and pairs of black holes are good candidates. In 1993, Russell Hulse and Joe Taylor were able to prove indirectly the existence of gravitational radiation. Hulse-Taylor binary [E3] consists of ordinary star and pulsar with the masses of stars around 1.4 solar masses. Their distance is only few solar radii. Note that the pulsars have small radius, typically of order 10 km. The distance between the stars can be deduced from the Doppler shift of the signals sent by the pulsar. The radiated power is about 10^{22} times that from Earth-Sun system basically due to the small value of R. Gravitational radiation induces the loss of total energy and a reduction of the distance between the stars and this can be measured.

5.1.2 How to detect gravitational radiation?

Concerning the detection of gravitational radiation the problems are posed by the extremely weak intensity and large distance reducing further this intensity. The amplitude of gravitational radiation is measured by the deviation of the metric from Minkowski metric, denote by h.

Weber bar [E2] provides one possible manner to detect gravitational radiation. It relies on a resonant amplification of gravitational waves at the resonance frequency of the bar. For a gravitational wave with an amplitude $h \sim 10^{-20}$ the distance between the ends of a bar with length of 1 m should oscillate with the amplitude of 10^{-20} meters so that extremely small effects are in question. For Hulse-Taylor binary the amplitude is about $h = 10^{-26}$ at Earth. By increasing the size of apparatus one can increase the amplitude of stretching.

Laser interferometers provide second possible method for detecting gravitational radiation. The masses are at distance varying from hundreds of meters to kilometers [E2]. LIGO (the Laser Interferometer Gravitational Wave Observatory) consists of three devices: the first one is located with Livingston, Lousiana, and the other two at Hanford, Washington. The system consist of light storage arms with length of 2-4 km and in angle of 90 degrees. The vacuum tubes in storage arms carrying laser radiation have length of 4 km. One arm is stretched and one arm shortened and the interferometer is ideal for detecting this. The gravitational waves should create stretchings not longer that 10^{-17} meters which is of same order of magnitude as intermediate gauge boson Compton length. LIGO can detect a stretching which is even shorter than this. The detected amplitudes can be as small as $h \sim 5 \times 10^{-22}$.

5.2 Quantum Mechanisms For The Emission Of Gravitational Radiation

Whether the classical gravitational radiation corresponds to that coming from the transitions between Bohr orbits is far from being a trivial question. At this moment it is not possible to calculate the transition rates but it turns out that $n = 3 \rightarrow 1$ transition is consistent with classical radiation formula for Hulse-Taylor binary [E3] under reasonable assumption about the reaction rate. Ordinary gravitational radiation could be also associated with the sequence of phase transitions reducing h_{gr}. Under same assumption the rate is of the same order of magnitude. Both options force to consider the possibility that gravitational radiation generated in spontaneous transitions is a rather rare phenomenon.

5.2.1 Some quantitative estimates for gravitational quantum transitions in planetary system

To get a concrete grasp about the situation it is useful to study the energies of dark gravitons in the case of planetary system assuming Bohr model.

The expressions for the energies of dark gravitons can be deduced from those of hydrogen atom using the replacements $Ze^2 \rightarrow 4\pi GMm$, $\hbar \rightarrow GMm/v_0$. The energies are given by

$$\begin{aligned} E_n &= \frac{1}{n^2}E_1 \ , \\ E_1 &= (Z\alpha)^2\frac{m}{4} = (\frac{Ze^2}{4\pi\hbar})^2 \times \frac{m}{4} \rightarrow \frac{m}{4}v_0^2 \ . \end{aligned} \tag{5.2}$$

E_1 defines the energy scale. Note that v_0 defines a characteristic velocity if one writes this expression in terms of classical kinetic energy using virial theorem $T = -V/2$ for the circular orbits. This gives $E_n = T_n = mv_n^2/2 = mv_0^2/4n^2$ giving

$$v_n = \frac{v_0}{\sqrt{2}n} \ .$$

Orbital velocities are quantized as sub-harmonics of the universal velocity $v_0/sqrt2 = 2^{-23/2}$ and the scaling of v_0 by $1/n$ scales does not lead out from the set of allowed velocities.

Bohr radius scales as

$$r_0 = \frac{\hbar}{Z\alpha m} \rightarrow \frac{GM}{v_0^2} \ . \tag{5.3}$$

For $v_0 = 2^{11}$ this gives $r_0 = 2^{22}GM \simeq 4 \times 10^6 GM$. In the case of Sun this is below the value of solar radius but not too much.

The frequency $\omega(n, n-k)$ of the dark graviton emitted in $n \to n-k$ transition and orbital rotation frequency ω_n are given by

$$\begin{aligned} \omega(n, n-k) &= \frac{v_0^3}{GM} \times (\frac{1}{n^2} - \frac{1}{(n-k)^2}) \simeq 2k\omega_n \ . \\ \omega_n &= \frac{v_0^3}{GMn^3} \ . \end{aligned} \tag{5.4}$$

The emitted frequencies at the large n limit are harmonics of the orbital rotation frequency so that quantum classical correspondence holds true. For low values of n the emitted frequencies differ from harmonics of orbital frequency.

The energy emitted in $n \to n-k$ transition would be

$$E(n, n-k) = mv_0^2 \times (\frac{1}{n^2} - \frac{1}{(n-k)^2}) \ , \tag{5.5}$$

and obviously enormous. Single giant (spherical) dark graviton would be emitted in the transition and should decay to gravitons with smaller values of $\hbar$. Bunch like character of the detected radiation might serve as the signature of the process. The bunch like character of liberated dark gravitational energy means coherence and might play role in the coherent locomotion of living matter. For a pair of systems of masses $m = 1$ kg this would mean $Gm^2/v_0 \sim 10^{20}$ meaning that exchanged dark graviton corresponds to a bunch containing about 10^{20} ordinary gravitons. The energies of graviton bunches would correspond to the differences of the gravitational energies between initial and final configurations which in principle would allow to deduce the Bohr orbits between which the transition took place. Hence dark gravitons could make possible the analog of spectroscopy in astrophysical length scales.

5.2.2 The power of graviton radiation emitted in the transition between two Bohr orbits

If dark matter is at stationary states and does not leak between pages of the Big Book with different Planck constant, it does not radiate at all except during the transitions reducing the value of n. Gravitational radiation would be emitted as bursts and these transitions need not have anything to do with quadrupole radiation.

The shortening of the orbital period of Hulse-Taylor binary can be explained with.2 per cent accuracy in terms of energy loss due to gravitational radiation so that the task is to check whether the average power from the transitions between Bohr orbits is consistent with the classical formula or not. To achieve this, one must estimate the average power associated with the transition $n \to n+k$ for the Bohr orbit model of a two-body system.

1. For the energy liberated energy as gravitational radiation one obtains

$$E_{tot} = E_n - E_{n-k} \ = \ \hbar_{gr}\omega = \frac{mv_0^2}{4}((n-k)^{-2} - n^{-2}) \simeq \frac{2kmv_0^2}{n^3} \ . \tag{5.6}$$

2. In order to estimate the average power of radiation one must have an estimate for the time T during which the radiation is emitted. $T \sim 2\pi/\omega$ gives lower bound for T. A more general guess is $T \simeq a(2\pi/\omega)v_0^{-p}$, where a is a numerical constant of order unity. This gives estimate for the total average power

$$\begin{aligned} P_q &\sim \frac{E_{tot}}{T} = \frac{\hbar_{gr}\omega^2 v_0^p}{2\pi a} = \frac{GMmv_0^{p+1}}{2\pi a r_n^2} F(n) \ , \\ F(n,k) &= ((\frac{n}{n-k})^2 - 1)^2 \simeq \frac{4k^2}{n^2} \ , \ r_n = n^2\frac{GM}{v_0^2} \ . \end{aligned} \tag{5.7}$$

r_n denotes the radius of n: th Bohr orbit. Note that P_q increases as n^2 for large values of n.

3. If the radius R in the formula for the quadrupole radiation powers is identified as Bohr radius r_{n-1}, the ratio of the power P_{cl} emitted by quadrupole radiation to P_q is

$$R \equiv \frac{P_{cl}}{P_q} \simeq ax \times y \times F(n,k)^{-1} \times v_0^{5-p} \ ,$$
$$x = \frac{2^6\pi}{5} \ , \ y = \frac{(M+m)m}{M^2} \ . \tag{5.8}$$

   The dependence on v_0 disappears for $p=5$. For a binary system with $m=M$ the orders of magnitude are same so that $p=5$ is the the unique choice of one wants an approximate consistency with the classical formula. For $M=m$, $(n,k)=(3,2)$, $n=3$, $(a,p)=(.796,5)$ gives $R=1$. For $(n,k)=(3,1)$ $a=.112$ is required for $R=1$. For larger values of n the needed value of a increases because R degreases as $1/n^4$.

For the Hulse-Taylor binary [E3] the masses are $1.441M_S$ and $1.387M_S$ and nearly identical. The semi-major axis is $R=1.95\times10^6$ km and the orbital period is $T=7.75$ hr. From $T=2\pi/\omega=2\pi GM(n/v_0)^3$ one can estimate $(n/v_0)^3$ using the mnemonic $r_s=2GM=(M/M_S)\times2.95$ km. This gives $v_0=n\times1.2\times10^{-3}$. From $r_n=n^2GM/v_0^2\sim R$ one obtains $v_0=n\times1.0\times10^{-3}$. These conditions are not actually independent. Assuming that $n=3\rightarrow1$ transition is in question one has $v_0\simeq3\times10^{-3}$. That v_0 is larger for Hulse-Taylor binary than solar system conforms with the general expectation that at black-hole limit v_0 approaches to $v_0=1$.

The estimated time before the final spiral takes place is $\tau=3\times10^8$ years. For the estimated value of v_0 the time for the transition between states n and $n-1$ would be $\tau\sim av_0^{-5}5T\simeq 2.8972\times10^9$ years, which is consistent with the classical estimate. It seems that the interpretation as quantum transition could make sense. If the interpretation is correct it could mean that gravitational radiation is rather rare phenomenon since the quantum transitions between stationary states are expected to be rare occurrences.

5.2.3 Could ordinary gravitational radiation be radiation emitted in the reduction of gravitational Planck constant

The Bohr model for Hulse-Taylor binary predicts a reasonable value of v_0 and the interpretation as a transition between Bohr orbits makes sense if the transition in question is $n=3\rightarrow1$ transition leading to the ground state. One can consider also other mechanism producing gravitational radiation.

1. The model for Hulse-Taylor and also other data suggest that v_0 increases as the planetary system gets older. This raises the possibility that gravitational radiation is emitted in transitions increasing the value of the velocity parameter v_0 as as dark matter leaks to the pages of the Big Book with smaller Planck constant. This assumption is consistent with second law and with the vision about how system approaches to chaos. If $1/v_0$ is integer the number of these transitions would be relatively small. If v_0 is a ratio of very big integers situation changes. v_0 cannot exceed light velocity so that in the limiting situation $v_0\leq1$ holds true. The asymptotic value $\hbar_{gr}\geq GMm$ and would make possible to avoid gravitational collapse. $v_0=1$ might have interpretation in terms of the light-likeness of the asymptotic wormhole throat containing only dark matter.

   After the asymptotic value of v_0 has been reached, the transitions could occur as transitions between Bohr orbits if one has $n>1$ in the original situation. This picture conforms with the idea that genuine quantum realm is realized only at the radii comparable to gravitational Planck length $L_{Pl}=\sqrt{\hbar_{gr}G}=G\sqrt{Mm}$. For $M=m$ this length is one half of Schwartschild radius.

2. Assume that all energy liberated in the transitions goes to gravitational radiation, and that the rate is determined by the condition $\tau=a\times2\pi v_0^5/\omega$. This gives

$$\hbar_{gr}\omega = \frac{m}{4}\frac{\Delta v_0^2}{n^2} \ . \tag{5.9}$$

This gives for the ratios of transition times and radiation powers in the two kinds of transitions the estimates

$$\frac{\tau_{\Delta v_0}}{\tau_{\Delta n}} = \frac{v_0^2}{n^2}\frac{\Delta(\frac{1}{n^2})}{\Delta v_0^2} ,$$
$$\frac{P_{\Delta v_0}}{P_{\Delta n}} = (\frac{v_0^2}{n^2}\frac{\Delta(\frac{1}{n^2})}{\Delta v_0^2})^2 . \quad (5.10)$$

The ratio is of order u power of radiated energy is of same order as in the previous case.

A couple of further remarks about the model are in order.

1. Bohr energies are proportional to $(\hbar_{gr}n)^{-2}$. In case of $F-C$ option this allows to consider the possibility that common factor drops out from both n and $1/hbar_{gr}$ without any change in the energy of the state since the Bohr orbit is not affected. The Planck constant for the outer planets in solar system is by a factor 5 larger than for inner planets and this kind of transition is in principle possible.

2. At formal level at least one can also consider gravitationally bound states of light particles. For $GMm < 1$ the value of gravitational Planck constant would becomes smaller than $\hbar_0$ for $v_0 \to 1$. In this case the asymptotic situation would correspond to $v_0 = GMm$.

One can consider also an alternative model in which one treats the change of v_0 as an effectively continuous process, drops the assumption about τ, and equates the radiation power to the classically predicted power.

1. The condition that $\hbar$ changes almost continuously combined with the condition $\hbar$ is reduced by dividing factors out from n_a and n_b requires that $\hbar$ contains a product of ratios of almost identical integers associated with n_a and n_b: $n_a/n_b = \prod_i(r_i/s_i)$, $r_i/s_i < 1$. This condition is quite stringent and one can argue that it makes the model un-natural.

2. Using $E_n = mv_0^2/4n^2$ for circular Bohr orbits, the power radiated as gravitational radiation would be

$$P_n = \frac{dE_n}{dt} = 2E_n\frac{dlog(v_0)}{dt} . \quad (5.11)$$

This gives

$$\frac{dlog(E_n)}{dt} = 2\frac{dlog(v_0)}{dt} = 2\frac{dlog(\frac{v_0}{n})}{dt} . \quad (5.12)$$

Note that the formula is scaling invariant.

3. Using classical radiation formula for which the radiated power is proportional to $1/r_n^5$ and $r_n = GMn^2/v_0^2$ one has $P_n \propto (v_n/n)^{10}$ and $P_n/E_n \propto (v_n/n)^8/n^2$. Combining this with the above result one has

$$\frac{dlog(x_n)}{dt} = \frac{k}{GMn^2}x_n^8 ,$$
$$x = \frac{v_0}{n} , \quad k = \frac{2^6}{5}(\frac{m}{M})^2\frac{M+m}{m} . \quad (5.13)$$

This gives

$$v_0 = n(\frac{v_0(0)}{n}^{-7} - 7k\frac{t}{GM})^{-1/7} \ . \tag{5.14}$$

The time devolution of v_0 depends on Bohr orbit. This conforms with the fact that to each planet there corresponds a particular space-time sheet mediating gravitational interaction. The different time dependence of v_0 for different Bohr orbits however implies that Bohr model with single value of v_0 cannot explain the radii of planetary orbits for large values of t. For $v_0(0) = 2^{-11}$ $v_0(0)^{-7}$ equals to 2^{77} so that the rate for the change is very slow.

4. The velocity becomes infinite in time

$$t_\infty = \frac{GM}{8k}\frac{v_0(0)}{n}^{-8} \ .$$

Light velocity of course sets an upper bound for the velocity and is never achieved and the formula most break down at relativistic velocities. A rough estimate for the time during which light velocity is achieved is as

$$t_1 = \frac{GM}{8k}(\frac{v_0(0)}{n}^{-8} - 1) \ .$$

The time depends on Bohr orbit.

5. The model does not say anything about the emission process itself. Gravitons could be also emitted as dark gravitons. The value of Planck constant for them must be however considerably smaller than the value of $\hbar_{gr}$.

5.3 Model For Dark Gravitons

If one wants to understand how dark gravitons possibly affect the standard predictions for graviton detection, one must develop a model for dark gravitons and their transformation to ordinary gravitons.

5.3.1 Gravitons in TGD

Unlike the naïve application of Mach's principle would suggest, gravitational radiation is possible in empty space in general relativity. In TGD framework it is not possible to speak about small oscillations of the metric of the empty Minkowski space imbedded canonically to $M^4 \times CP_2$ since Kähler action is non-vanishing only in fourth order in the small deformation and the deviation of the induced metric is quadratic in the deviation. Same applies to induced gauge fields. Even the induced Dirac spinors associated with the Kähler-Dirac action fixed uniquely by super-symmetry allow only vacuum solutions in this kind of background. Mathematically this means that both the perturbative path integral approach and canonical quantization fail completely in TGD framework. This led to the vision about physics as Kähler geometry of "world of classical worlds" with quantum states of the universe identified as the modes of classical WCW spinor fields.

The resolution of various conceptual problems is provided by the parton picture and the identification of elementary particles as light-like 3-surfaces associated with the wormhole throats. Gauge bosons correspond to pairs of wormholes and fermions to topologically condensed CP_2 type extremals having only single wormhole throat.

Gravitons are string like objects in a well defined sense. This follows from the mere spin 2 property and the fact that partonic 2-surfaces allow only free many-fermion states. This forces gauge bosons to be wormhole contacts whereas gravitons must be identified as pairs of wormhole contacts (bosons) or of fermions connected by flux tubes. The strong resemblance with string models encourages to believe that general relativity defines the low energy limit of the theory. Of course, if one accepts dark matter hierarchy and dynamical Planck constant, the notion of low energy limit itself becomes somewhat delicate.

5.3.2 The number of states is conserved in the phase transitions changing Planck constant

The number of states is conserved in phase transitions changing Planck constant as the following argument demonstrates.

1. The units of charges are scaled by $1/n_i$ for the covering space option (C) and by n_i for factor space option (F). Without any constraints the number of states would be scaled by n_i for C and $1/n_i$ for F. The modification of fermionic anti-commutation (bosonic commutation) relations involving $\hbar$ at the right hand side implies that particle numbers become as multiples of $\hbar/\hbar_0$ so that particle number is fractionized in the general case. This implies a change in the number of states which compensates the change caused by the change of the charge units so that the total number of states remains unchanged in the phase transitions affecting the value of $\hbar$.

2. For F-option particle number becomes fractional implying that angular momentum and charge units are not changed. If the anyonic state is created from an ordinary one in a phase transition, the total particle number for the entire anyonic state must be integer, which gives rise to a confinement mechanism. For C-option the charge units are fractional but since particle numbers become as integer multiples of n_i, the net result is that total charges have the standard spectrum. Single particle states can however have fractional charges. In anyonic many-particle states this kind of spin and charge fractionization can take place at single particle level [K22].

3. If one assumes G_i-singletness for the states of the covering, the unit of angular momentum is scaled up by n_i and the interpretation is in terms of n_i copies of ordinary single particle states at the sheets of the covering. For factor space option already single particle states are by definition G_i singlets.

5.3.3 What kind of dark gravitons can one consider?

First of all one must decide what sector of the generalized embedding space dark graviton correspond to. There are four options of which two ($C-C$ and $F-C$) can give rise to large angular momentum and only these options will be discussed in the sequel. It should be noticed that if one accepts the proposal that the hierarchy of Planck constants follows from basic TGD then only the $C-C$ option remains. This option is favored also because it implies evolution as increase of Planck constants and because for given value of Planck constant there is only a finite number of different pages of the Big Book corresponding to the factorizations of $n = n_a n_b$ of the integer $n = \hbar/\hbar_0$.

1. $C-C$ option corresponds to Planck constant $r \equiv \hbar/\hbar_0 = n_a n_b$. Both G_a and G_b would act in their respective covering spaces assignable to the gravitational field body. Either n_a or n_b or both must be very large. For large n_b G_a singletness implies that the unit of angular momentum of the giant graviton is proportional to n_b and thus very large and the interpretation is as a bundle of ordinary gravitons. In this case also gravitons with small net angular momentum are possible.

2. $F-C$ option: corresponds to $\hbar/\hbar_0 = n_b/n_a$ with very large value of n_b. In this case graviton has G_a-fold rotational symmetry and would have very large angular momentum proportional to n_b.

Consider first the general view about de-coherence process assumed to reduce the symmetries defined by G_a and G_b.

1. Assuming singletness with respect to G_a and G_b, de-coherence could be seen as a sequence of symmetry breakdowns for both coverings and factor spaces. At given step the orders of the resulting symmetry groups G_a and G_b are divisors of the orders of the original groups. The final step would lead to trivial covering and factor spaces. Number theoretically the process is like determining the factors of a very large number by dividing them away in the de-coherence process.

2. Once the sector of the generalized embedding space is selected, one has still two options corresponding to spherical and plane waves. Spherical dark gravitons could be emitted in quantum transitions of the dark part of the astrophysical object. Emission process could also yield a sufficiently large number of MEs (massless extremals/ topological light rays [K14]) with large value of $\hbar$.

3. Spherical dark graviton can de-cohere into spherical gravitons with smaller groups G_a and G_b. Sooner or later spherical giant graviton must de-cohere into topological light rays ("MEs") defining the TGD counterparts of plane waves of finite width and define second model for dark graviton. They are expected to be detectable by human built detectors. Note that for $F-C$ option the meaning of G_a for the MEs is different from that for spherical gravitons since the directions of quantization axes of angular momentum are in general different.

5.3.4 Emission of dark gravitons

One must answer several non-trivial questions if one is to defend dark gravitational radiation.

Frequencies of dark gravitons turn out to correspond to orbital frequencies at large quantum number limit. However, if gravitational radiation is emitted as dark gravitons, they have enormous energies since the energy must correspond to the change of the energy of an astrophysical object jumping to a smaller Bohr orbit.

Hulse-Taylor binary system was used to demonstrate that the energy loss of the binary system equals to the classically predicted power of gravitational radiation. The power of gravitational radiation was deduced from the gradual reduction of the distance between the two stars. The obvious question is whether the consistency of the power emitted by Hulse-Taylor binary with the prediction of the classical theory kills the hypothesis about gigantic gravitational Planck constant.

1. If one assumes that v_0 is of same order of magnitude as for planetary systems as the value of the orbital radius indeed suggests, single spherical dark graviton emitted in the transition would carry away an essentially astrophysical energy. If MEs are emitted and one assumes that sufficiently high number of them is emitted so that the total recoil momentum is small.

2. If dark graviton is spherical or -more generally - corresponds to a partial wave with a definite value of angular momentum (in a sense to be specified), it must decay gradually to spherical or ME type gravitons with smaller values of Planck constant. The measurement process should induce this kind of decay.

3. The prediction that energy is emitted in bunches should have testable experimental implications. The case of hydrogen atom inspires the question whether the lowest orbit is stable and does not emit gravitational radiation meaning that the binary ends up to the stable state rather than collapsing. Of course, the idealization as hydrogen atom like system might fail. The identification of dark gravitons as dark topological light rays (massless extremals, MEs) containing topologically condensed ordinary gravitons will be discussed later.

By quantum classical correspondence this process must have a space-time description.

1. The natural proposal is that below the time scale associated with the emission process the space-time picture about the emission process looks like a continuous process, at least asymptotically when the space-time itself is replaced repeatedly with a new one. Thus the transition between orbitals at the level of space-time correlates must occur continuously below the time scale assigned to it classically. Quantum emission would quite generally mean in sub-quantum time scales continuous classical process at space-time level.

2. TGD based quantum model for living system suggests that the transition occurs in a fractal manner proceeding from long to short dark time scales. First a quantum jump in the longest time scale occurs and induces the replacement of the entire space-time with a new one differing dramatically from the previous one. This quantum jump is followed by quantum jumps in shorter time scales. At each step space-time sheet characterizing the system is replaced by a new one and eventually by a space-time surface which describes the process as more or less continuous one. The final space-time could be regarded as symbolic description of the process as a classical continuous process.

3. The time interval for the occurrence of the transition at space-time level should correspond to a dark p-adic time scale and in the case of Hulse-Taylor binary be of same order as the lifetime of the period during which the system ends up to a stable state. In the Hulse-Taylor case the emission would correspond to small values of n, most naturally $n = 2 \rightarrow n = 1$ transition so that the frequency of the gravitational radiation would not correspond to the orbital frequency. This might some day be used as a test for the theory. The time duration T for the transition can be estimated from $T = \Delta E/P$, where P is the classical formula for the emission power.

5.3.5 Model for the spherical graviton

Detector, giant graviton, source, and topological light ray will be denoted simply by D, G, and S, and ME in the following. Consider first the model for the giant graviton.

1. Orbital plane defines the natural quantization axis of angular momentum for spherical graviton. Spherical graviton corresponds to a graviton with very large unit of angular momentum corresponding to G_a invariance acting in covering space degrees of freedom but can be regarded as a Bose-Einstein condensate like state of ordinary gravitons.

2. The total angular momentum of the giant graviton(s) must correspond to the change of angular momentum in the quantum transition between initial and final orbit. Orbital angular momentum in the direction of quantization axis should be a small multiple of dark Planck constant associated with the system formed by giant graviton and source. These states correspond to Bose-Einstein condensates of ordinary gravitons in eigen state of orbital angular with ordinary Planck constant. Unless S-wave is in question the intensity pattern of the gravitational radiation depends on the direction in a characteristic non-classical manner. The coherence of dark graviton regarded as Bose-Einstein condensate of ordinary gravitons is what distinguishes the situation in TGD framework from that in GRT.

5.3.6 Dark graviton as topological light ray

Second kind of dark graviton is analog for plane wave with a finite transversal cross section. TGD indeed predicts what I have called topological light rays, or massless extremals (MEs) as a very general class of solutions to field equations [K14].

MEs are typically cylindrical structures carrying induced gauge fields and gravitational field without dissipation and dispersion and without weakening with the distance. These properties are ideal for targeted long distance communications which inspires the hypothesis that they play a key role in living matter [K11, K2] and make possible a completely new kind of communications over astrophysical distances. Large values of Planck constant allow to resolve the problem posed by the fact that for long distances the energies of these quanta would be below the thermal energy of the receiving system.

Giant gravitons are expected to decay to this kind of dark gravitons having smaller value of Planck constant via de-coherence and that it is these gravitons which are detected. Quantitative estimates indeed support this expectation.

The same general picture that applies to spherical gravitons applies to MEs. The only difference is that quantization axis of angular momentum left point-wise invariant under G_a is parallel to the direction of propagation. Thus the de-coherence of a spherical graviton into MEs means dispersion to a sector of the world of classical worlds possessing different quantization axes.

5.4 Detection Of Gravitational Radiation

One should also understand how the description of the gravitational radiation at the space-time level relates to the picture provided by general relativity to see whether the existing measurement scenarios really measure the gravitational radiation as they appear in TGD. There are more or less obvious questions to be answered (or perhaps obvious after a considerable work).

What is the value of dark gravitational constant which must be assigned to the pair formed by the measuring system and gravitational radiation from a given source? Is the detection of primary giant graviton possible by human means or is it possible to detect only dark gravitons produced in the sequential de-coherence of giant graviton? Do dark gravitons enhance the possibility to detect gravitational radiation as one might expect? What are the limitations on detection due to energy conservation in de-coherence process?

5.4.1 TGD counterpart for the classical description of detection process

The oscillations of the distance between the two masses defines a simplified picture about the receival of gravitational radiation.

Now ME would correspond to n_a-sheeted covering of M^4 analogous to Riemann space associated with n_a:th root of z with each sheet oscillating with the same frequency: simply a stack of ordinary MEs defining a bundle of ordinary gravitons. Classical interaction would suggest that the measuring system topologically condenses at the topological light ray so that the distance between the test masses measured along the topological light ray in the direction transverse to the direction of propagation starts to oscillate. This (or these) topological light rays must however result via de-coherence to $n_a = n_b = 1$ sector of the embedding space unless measurement system itself corresponds to dark matter. If only single topological light ray results it must carry large number of gravitons. Topological light rays can be indeed regarded as space-time correlates for massless collinear bosons of various kinds. One can also consider the possibility that measurement system is quantum critical itself.

Obviously the classical behavior is essentially the same as predicted by general relativity. If all elementary particles are maximally quantum critical systems and therefore also gravitons, then gravitons can be absorbed at each step of the process, and the number of absorbed gravitons and energy is N-fold.

One can ask whether one should treat the detector as a $(n_a, n_b) = (1, 1)$ system or whether one could assume that the Planck constant is large and given by a formula $\hbar(D)/\hbar_0 = GM^2(D)/v_D$ so that the gravitational field body would catch the incoming dark graviton. In this case the value of $\hbar$ for incoming gravitons should be equal to $\hbar(D)$. This number theoretic condition is not in general true. Unless the gravitational field body of the detector is quantum critical in the sense of having branches in a large number of pages of the Big Book, this kind of detection is not possible in general and gravitons must end up to ordinary gravitons or gravitons with relatively small value of $\hbar$ before they can be detected.

5.4.2 The time interval during which the interaction with dark graviton takes place?

If the duration of the bunch is $T = E/P$, where P is the classically predicted radiation power in the detector and T the detection period, the average power during bunch is identical to that predicted by GRT. Also T would be proportional to r, and therefore code information about the masses appearing in the sequential de-coherence process.

An alternative, and more attractive possibility, is that T is same always and correspond to $r = 1$. The intuitive justification is that absorption occurs simultaneously for all r "Riemann sheets". This would multiply the power by a factor r and dramatically improve the possibilities to detect gravitational radiation. The measurement philosophy based on standard theory would however reject these kind of events occurring with $1/r$ time smaller frequency as being due to the noise (shot noise, seismic noise, and other noise from environment). This might relate to the failure to detect gravitational radiation.

5.5 Quantitative Model

In this subsection a rough quantitative model for the de-coherence of giant (spherical) graviton to topological light rays (MEs) is discussed and the situation is discussed quantitatively for hydrogen atom type model of radiating system. The basic assumption is irreversibility in the sense that the integers n_a and n_b approach to unity in the de-coherence process.

5.5.1 Restrictions of the model

The model has important restriction, which is obvious after ten years from its formulation.

1. It is assumed that the emitter begins as a coherent object with mass m, which is astrophysical. Equivalence Principle allows also to consider emission by individual microscopic particles by just replacing the mass of the astrophysical object with the mass of microscopic particle and summing over the emissions of individual particles. The energy carried by dark graviton would correspond to the change of energy for particle dropping from Bohr orbit to a lower one: this is clearly much smaller. The important aspect is quantization of the energies of the emitted radiation which might be of importance as far as detection of the emitted radiation is considered if the value of the principal quantum number is not very large.

2. The order of magnitude is $\Delta E \sim m\Delta v^2$. The formula $\Delta E = \hbar_{gr}\omega$ gives $\omega \sim 2v_0\Delta(v^2/c^2)/r_S$, where Schwartschild radius $r_S = 2GM$ appears ($c = 1$ in the units used). Since all particles are transferred simultaneously to the lower orbit, the energy changes associated with individual particles add up to the energy resulting also by assuming quantum coherence for the entire object but now emitted as single giant graviton.

3. Obviously the model assuming a large number of dark gravitons associated with individual particles conforms better with physical intuitions but still predicts that gravitons are energetic and decay to bunches of ordinary gravitons in detector.

The following discussion is for giant gravitons but easily adapted to the situation in which microscopic objects are the emitters. The model also applies on the dark portion of matter in the rotating object. For ordinary matter the standard classical description of emission can be applied.

5.5.2 De-coherence of spherical dark gravitons to ordinary gravitons

The proposed general model for de-coherence can be applied to build a model for the de-coherence of spherical dark gravitons to ordinary spherical gravitons.

1. For $C - C$ option one can assume that de-coherence occurs through the decays of gravitons to multi-graviton states with smaller $\hbar$. These decay sequences correspond to all possible factorizations of the integer $N = n_a n_b$ to a product $N = \prod n_i$ of factors (same factor can appear several times) and taken in all possible orders distinguishable from each other. A particular decay sequence means following. At the first step any factor n_i is divided from N producing a bundle of n_i gravitons with energy E/n_i. Briefly: $N \rightarrow N/n_i$, $E \rightarrow E/n_i$. This corresponds to a node of a tree with incoming graviton defining the root and having n_i branches. This process repeats itself for each new branch independently creating new branches at each node. This process repeats itself until only ordinary gravitons are left. Note that the last decay could take place at detector. This picture suggests that the flow of ordinary gravitons is not steady but takes place in bunches of ordinary gravitons so that standard detector arrangements might regard these bunches as noise.

2. For $F - C$ option one has $r = n_b/n_a$ which corresponds to non-integer valued graviton number. n_a is eliminated by a sequence of divisions of n_a by its factors and also now all possible sequences are possible. In this case graviton does not decay to multi-graviton state but suffers only a leakage to a sector with a smaller value of n_a so that frequency is scaled as $f \rightarrow f/n_i$, n_i a factor of n_a. The eventual replacement of the original frequency with its sub-harmonic f/n_a means that at least for large enough values of n_a the standard measurement arrangements estimating the typical value of f from orbital period fail to detect gravitons. If ruler and compass rule holds true, the analogy with the approach to chaos by period doubling is obvious.

3. The estimate for the number of ordinary gravitons gives estimate for the radiated energy per solid angle. This estimate follows also from the energy conservation for the transition. The requirement that average power equals to the prediction of GRT allows to estimate the geometric duration associated with the transition. The condition $\hbar\omega = E_f - E_i$ is consistent with the identification of $\hbar$ for the pair of systems formed by giant-graviton and emitting system.

5.5.3 Transformation of spherical giant gravitons to topological light-rays

The model for the transformation of dark spherical gravitons to ordinary gravitons via a transition to MEs differs from the above model only in that there is a step in which a transformation to MEs takes place.

1. Giant graviton leaks to sectors of H with a smaller value of Planck constant via quantum critical points common to the original and final sector of H. If ordinary gravitons are quantum critical they can be regarded as leakage points.

2. It is natural to assume that the resulting dark graviton corresponds to a radial topological light ray (ME).

3. Energy should be conserved in the leakage process. The secondary dark graviton receives the fraction $\Delta\Omega/4\pi = S/4\pi r^2$ of the energy of giant graviton, where $S(ME)$ is the transversal area of ME, and r the radial distance from the source, of the energy of the giant graviton. Energy conservation gives

$$\frac{S(ME)}{4\pi r^2}\hbar(G,S)\omega \quad = \quad \hbar(G,ME)\omega \ , \tag{5.15}$$

where S and ME refer to spherical and ME. From this one obtains

$$\frac{S(ME)}{4\pi r^2} \quad = \quad \frac{\hbar(G,ME)}{\hbar(G,S)} \simeq \frac{E(ME)}{M(S)} \ . \tag{5.16}$$

The larger the distance is, the larger the area of ME. This means a restriction to the measurement efficiency at large distances for realistic detector sizes since the number of gravitons must be proportional to the ratio $S(D)/S(ME)$ of the areas of detector and ME.

4. After the transformation to MEs the MEs decay to bundles of MEs with smaller value of $\hbar$ just as spherical gravitons would do. The values of $\hbar$ appearing in the sequence are same as for spherical cascade.

5.5.4 Estimate for the total number of detected ordinary gravitons

For $F-C$ option the frequencies of detected gravitons are sub-harmonics f/n_a. For $C-C$ option the frequency is the original one. Suppose that the detector has a disk like shape with disk radius d. This gives for the total number $n(D)$ of ordinary gravitons going to the detector the estimate

$$n(D) \quad = \quad \frac{\Delta\Omega}{4\pi\times n_b(G,S)} = \frac{1}{4}\times(\frac{d}{r})^2\times n_b(G,S) \ , \tag{5.17}$$

This implies

$$\begin{aligned} n(D) \quad &= \quad x\frac{GMm}{v_0}\frac{1}{4}\times(\frac{d}{r})^2 \ , \\ x = 1 \ \text{ for } C-C \text{ option}, \ \ x = n_a \ &\text{ for } F-C \text{ option} \ . \end{aligned} \tag{5.18, 5.19}$$

If the actual area of detector is smaller than d^2 by a factor x one has

$$n(D) \rightarrow xn(D) \ .$$

$$E(D) \quad = \quad E_{tot} \times \frac{1}{4}(\frac{d}{r})^2 \quad , \quad E_{tot} = \hbar_{gr}\omega \quad , \quad \frac{GMm}{v_0} \quad . \tag{5.20}$$

Assuming that the radiation is emitted during time $T \sim 2\pi/\omega$ on obtains the estimate for the total power

$$P_q \quad \sim \quad \frac{E_{tot}}{T} = \frac{1}{2\pi}\hbar_{gr}\omega^2 \quad . \tag{5.21}$$

5.6 Generalization To Gauge Interactions

The situation is expected to be essentially the same for gauge interactions. The first guess is that one has $r = Q_1Q_2g^2/v_0$, were g is the coupling constant of appropriate gauge interaction. v_0 need not be same as in the gravitational case. The value of $Q_1Q_2g^2$ for which perturbation theory fails defines a plausible estimate for v_0. The basic constraint is $v_0 \leq 1$. In the case of gravitation this interpretation would mean that perturbative approach fails for $GM_1M_2 = v_0$. For $r > 1$ Planck constant is quantized with rational values with ruler-and-compass rationals as favored values. For gauge interactions r would have rather small values. The above criterion applies to the field body connecting two gauge charged systems. One can generalize this picture to self interactions assignable to the "personal" field body of the system. In this case the condition would read as $\frac{Q^2g^2}{v_0} > 1$.

5.6.1 Some applications

One can imagine several applications.

1. A possible application would be to electromagnetic interactions in heavy ion collisions.

2. Gamma ray bursts might be one example of dark photons with very large value of Planck constant. The MEs carrying gravitons could carry also gamma rays and this would amplify the value of Planck constant form them too.

3. Atomic nuclei are good candidates for systems for which electromagnetic field body is dark. The value of $\hbar$ would be $r = Z^2e^2/v_0$, with $v_0 \sim 1$. Electromagnetic field body could become dark already for $Z > 3$ or even for $Z = 3$. This suggest a connection with nuclear string model [K19] in which $A \leq 4$ nuclei (with $Z < 3$) form the basic building bricks of the heavier nuclei identified as nuclear strings formed from these structures which themselves are strings of nucleons.

4. Color confinement for light quarks might involve dark gluonic field bodies.

5. Dark photons with large value of $\hbar$ could transmit large energies through long distances and their phase conjugate variants could make possible a new kind of transfer mechanism [K7] essential in TGD based quantum model of metabolism and having also possible technological applications. Various kinds of sharp pules [H1] suggest themselves as a way to produce dark bosons in laboratory. Interestingly, after having given us alternating electricity, Tesla spent the rest of his professional life by experimenting with effects generated by electric pulses. Tesla claimed that he had discovered a new kind of invisible radiation, scalar wave pulses, which could make possible wireless communications and energy transfer in the scale of globe (for a possible but not the only TGD based explanation [K5]). This notion of course did not conform with Maxwell's theory, which had just gained general acceptance so that Tesla's fate was to spend his last years as a crackpot. Great experimentalists seem to be able to see what is there rather than what theoreticians tell them they should see. They are often also visionaries too much ahead of their time.

5.6.2 In what sense dark matter is dark?

The notion of dark matter as something which has only gravitational interactions brings in mind the concept of ether and is very probably only an approximate characterization of the situation. As I have been gradually developing the notion of dark matter as a hierarchy of phases of matter with an increasing value of Planck constant, the naïvete of this characterization has indeed become obvious.

If the proposed view is correct, dark matter is dark only in the sense that the process of receiving the dark bosons (say gravitons) mediating the interactions with other levels of dark matter hierarchy, in particular ordinary matter, differs so dramatically from that predicted by the theory with a single value of Planck constant that the detected dark quanta are unavoidably identified as noise. Dark matter is there and interacts with ordinary matter and living matter in general and our own EEG in particular provide the most dramatic examples about this interaction. Hence we could consider the dropping of "dark matter" from the glossary altogether and replacing the attribute "dark" with the spectrum of Planck constants characterizing the particles (dark matter) and their field bodies (dark energy).

In many-sheeted space-time particles topologically condense at all space-time sheets having projection to given region of space-time so that this option makes sense only near the boundaries of space-time sheet of a given system. Also p-adic phase transition increasing the size of the space-time sheet could take place and the liberated energy would correspond to the reduction of zero point kinetic energy. Particles could be transferred from a portion of magnetic flux tube portion to another one with different value of magnetic field and possibly also of Planck constant h_{eff} so that cyclotron energy would be liberated.

5.7 Can Graviton Have Mass?

The latest news from LIGO is that it has not detected gravitational waves from black holes with masses in the range 25-100 solar masses [E12]. This conforms with theoretical predictions. Earlier searches from Super Novae give also null result: in this case the searches are already at the boundaries of resolution so that one can start to worry.

The reduction of the spinning rate of Hulse-Taylor binary (see `http://tinyurl.com/yc8gmood`) [E3] is consistent with the emission of gravitational waves with the predicted rate so that it seems that gravitons are emitted. One can however ask whether gravitational waves might remain undetected for some reason.

Massive gravitons is the first possibility. For a nice discussion see the article of Goldhaber and Nieto (see `http://tinyurl.com/ycwr2v2d`) [E21] giving in their conclusions a table summarizing upper bounds on graviton mass coming from various arguments involving model dependent assumptions. The problem is that it is not at all clear what massive graviton means and whether a simple Yukawa like behavior (exponential damping) for Newtonian gravitational potential is consistent with the general coordinate invariance. In the case of massive photons one has similar problem with gauge invariance. One can of course naïvely assume Yukawa like behavior for the Newtonian gravitational potential and derive lower bounds for the Compton wave length of gravitons. The bound is given by $\lambda_c \geq 100$ Mpc.

Second bound comes from the pulsar timing measurements (see `http://tinyurl.com/ydhbbfd7`) [E16]. The photons emitted by the pulsar are assumed to surf in the sea of gravitational waves created by the pulsar. If gravitons are massive in Yukawa sense they arrive with velocities which are below light velocity, a dispersion of both graviton and photon arrival times is predicted. This gives a much weaker lower bound $\lambda_c \geq 1$ pc. Note that the distance of Hulse-Taylor binary is 6400 pc so that this upper bound for graviton mass could explain the possible absence of gravitational waves from Hulse-Taylor binary. There are also other bounds on graviton mass (see `http://tinyurl.com/ycwr2v2d`) [E21] but all are plagued by model dependent assumptions.

Also in TGD framework one can imagine explanations for the possible absence of gravitational waves. I have already discussed the possibility that gravitons are emitted as dark gravitons with gigantic value of $\hbar$, which decay eventually to bunches of ordinary gravitons meaning that continuous stream of gravitons is replaced with bursts which would not be interpreted in terms of gravitons but as noise.

One of the breakthroughs of the last year was related to the twistor approach to TGD [K27] in zero energy ontology (ZEO).

1. This approach leads to the vision that all building blocks (light-like wormhole throats) of physical particles -including also virtual particles and also string like objects- are massless. On mass shell particles are bound states of massless particles but virtual states do not satisfy bound state constraint and because negative energies are possible, also space-like virtual momenta are possible.

2. Massive physical particles are identified as bound states of massless wormhole throats: since the three momenta can have different (as a special case opposite) directions, the bound states of light-like wormhole throats can be indeed massive.

3. Masslessness of the fundamental objects saves from problems with gauge invariance and general coordinate invariance. It also makes it possible to apply twistor formalism, implies the absence of UV divergences, and yields an enormous simplification of generalized Feynman diagrammatics since mass shell constraints are satisfied at lines besides momentum conservation at vertices.

4. A simple argument forces to conclude that all spin one and spin two particles- in particular graviton- identified in terms of multi-wormhole throat states must have arbitrary small but non-vanishing mass. The resulting physical IR cutoff guarantees the absence of IR divergences. This allows to preserve the exact Yangian symmetry of the M-matrix. One implication is that photon eats the TGD counterpart of the neutral Higgs and that only pseudo-scalar counterpart of Higgs survives. The scalar counterparts of gluons suffer the same fate whereas their pseudo-scalar partners would survive.

Is the massivation of gauge bosons and gravitons in this sense consistent with the Yukawa type behavior?

1. The first thing to notice is that this massivation would be essentially a non-local quantal effect since both emitter and receiver both emit and receive light-like momenta. Therefore the description of the massivation in terms of Yukawa potential and using ordinary QFT might well be impossible or be a good approximation at best.

2. If the massive gauge bosons (gravitons) correspond to wormhole throat pair (pair of these) such that the three-momenta are light-like but in exactly opposite directions, no Yukawa type screening and velocity dispersion should take place.

3. If the three momenta are not exactly opposite as is possible in quantum theory, Yukawa screening could take place since the classical cm velocity calculated from the total momentum for a massive particle is smaller than maximal signal velocity. The massivation of intermediate gauge bosons and the fact that Yukawa potential description works for them satisfactorily supports this interpretation.

4. If the space-time sheets mediating gravitational interaction have gigantic values of gravitational Planck constant Compton length of graviton is scaled up dramatically so that screening would be absent but velocity dispersion would remain. This leaves open the possibility that gravitons from Hulse-Taylor binary could reveal the velocity dispersion if they are detected some day.

6 The TGD view of the recently discovered gravitational hum as gravitational diffraction

Year 2022 initiated a revolution in cosmology when James Webb telescope started to function [K26] [L6]. This is not the only big step of progress. The latest breakthrough related to the detection of gravitational hum was announced June 29 2023 [E14] (`rb.gy/e226v`: see also `rb.gy/vcm28` and `rb.gy/i4msf`).

6.1 The discovery

Scientists from the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) have now officially made the first detections of the gravitational wave background. This gravitational hum was not detected by Earth bound instruments. Rather, they make themselves manifest as periodic changes of the spinning rates of pulsars with the frequencies of the gravitational waves involved. The periods are of order year. In the LIGO experiment the periods are measured as fractions of a second.

The wavelength of the oscillations makes itself visible as correlations between the variations of the spinning rates for pulsars having relative distances measured using a light year as a unit. The wavelength of the oscillations is measured in light years. Where could this length scale come from? What might make bells ringing is that the star nearest to the Sun is at a distance of 4 light years and the typical distance between stars is 5 light years.

The unexpectedly large amplitude of the oscillations motivates the hypothesis that pairs of galactic supermassive blackholes or interacting groups of them could generate the gravitational hum. There are candidates for these pairs but no established pair. The group hypothesis seems to work better.

6.2 TGD explanation in terms of astrophysical gravitational quantum coherence and diffraction in hyperbolic tessellation

TGD suggests a radically different hypothesis based on TGD view of gravitational quantum coherence an diffraction in a hyperbolic tessellation.

1. TGD predicts quantum gravitational coherence in astrophysical scales characterized by gravitational Planck constants $h_{gr} = GMm/\beta_0$ characterizing big mass M and small mass m. $\beta_0 = v_0/c < 1$ ia velocity parameter. The Equivalence Principle is realized as the independence of the gravitational Compton length $\Lambda_{gr} = GM/\beta_0 = r_s/2\beta_0$ on mass m.

   (a) For the Sun with $\beta_0 \simeq 2^{-11}$ gravitational Λ_{gr} is 1/2 of Earth radius. According to the TGD proposal, which explains the Cambrian explosion in terms of rapid increase of the Earth radius by factor 2, this scale is the radius of Earth before the explosion [K6].

   (b) For Earth with $\beta_0 = 1$, the scale is .45 cm and the size scale of a snowflake, which is a zoomed version of the unit cell of the ice crystal: a fact which still remains a mystery.

   (c) For the galactic black hole with $\beta_0 = 1$, Λ_{gr} is about $1.2 \times 10^7 km = 1.2 \times 10^{-2}$ light seconds and corresponds to a frequency of about 100 Hz, the upper bound of EEG frequencies by the way (which might put bells ringing!). For $\beta_0 = 1$, Λ_{gr} happens to correspond to the radius of the lowest Bohr orbit for Sun Λ_{gr} in the Bohr orbit model for planetary orbit (another bell ringing!) and defines a lower bound for the quantum coherence scale.

   (d) For the Milky Way with a mass of $2 \times 10^{12} M_{Sun}$, Λ_{gr} is about 2×10^4 second and still much shorter than a few years' scale.

2. Where does the wavelength of order of distance between stars emerge? TGD strongly suggests that the tessellations (lattices) associated with hyperbolic 3-spaces define light-cone proper time a= constant surface play a key role in all scales, in particular in biology.

   There could exist a fractal hierarchy of tessellations (`rb.gy/yqd1l`) formed by astrophysical objects of various mass scales. Could the stars with average distance of 5 light years form tessellations of this kind analogous to lattices in a condensed matter system. The wavelength for the diffracted gravitational waves in cubic tessellation would have the upper bound 2d, d the lattice constant, which would be now about 5 light years.

3. There is empirical evidence for these tessellations. So called cosmic fingers, discovered by Halton Arp [L4] [K24], correspond to astrophysical objects appearing at single light of sight (first mystery) and having redshift coming as multiples of a basic redshift (second mystery). This could serve as a direct signature of the hyperbolic counterpart for a line of atoms located along a lattice. Redshift is proportional to distance and also to the recession velocity, which would therefore be quantized in the observed manner.

4. What kind of tessellations could be involved? There is an infinite number of tessellations for H^3 but only 4 regular uniform honeycombs. For two of them the unit cell is dodecahedron, for the remaining two it is icosahedron (I) or cube (C). Note that in Euclidian 3-space one has just one regular honeycomb consisting of cubes.

   There are also more general uniform honeycombs involving several cell types. There is a unique "multicellular" honeycomb for which all cells are Platonic solids: for other tessellations all cells are not Platonic solids (`rb.gy/t3c88`) . This is icosatetrahedral (or more officially, tetrahedral-icosatetrahedral) honeycomb for which the cells are tetrahedrons, octahedrons, and icosahedrons. All faces are triangles and I have proposed a universal realization of genetic code in which genetic codons correspond to the triangular faces of icosahedra and tetrahedra.

6.2.1 Gravitational diffraction as an amplification and guiding mechanism

The key prediction is gravitational diffraction in this cosmic lattice.

1. In lattice diffraction, the diffracted amplitude concentrates in specific directions corresponding to the reciprocal lattice. Something analogous should happen for tessellations in hyperbolic 3-space. Already the concentration to beams would mean an amplification effect (note that the lowest order prediction for the intensity of the radiation does not depend on the value of effective Planck constant).

   Furthermore, by quantum coherence the scattered amplitude is proportional to N^2 rather than N, where N is the number of atoms in the lattice, now stars in the tessellation. Could these two amplification effects explain why the observed effect is so much larger than expected? Professionals could easily find whether this idea fails at the quantitative level.

   The TGD view suggests that the dark gravitational radiation propagates along the monopole flux tubes connecting stars.

2. In the ordinary diffraction from a cubic lattice in Euclidean space E^3 , the condition of constructive interference for the two rays scattered from to neighboring points of the cubic lattice states, requires that the difference of lengths for the paths travelled is a multiple of the wavelength of the incoming radiation. This gives the Bragg condition: $sin(\theta) = n\lambda/2d$, where θ is the glance angle defined as the angle of incoming ray with respect to the normal direction of the lattice plane. The condition gives $\lambda < 2d/n$ and implies $\lambda < 2d$ for $n = 1$. Therefore the diffraction occurs only for frequency $\omega \geq n\omega_n$, $\omega_n > c/2d$.

   In the case of gravitational radiation, this would give for a cubic lattice $\lambda < 2d/n$, $d \sim 5$ light years, which conforms with the scale of a few years for the periods. The lower bound for the period T would be about $T_{min} = 10$ years. The condition that the scattered beams connect lattice points, gives an additional quantization condition to the glance angle θ. Most naturally it would correspond to a line connecting lattice points.

6.2.2 Trillions of stars mysteriously disappearing from the sight of James Webb Telescope!

James Webb Telescope is revolutionizing our world view. Now it tells about disappearing stars (see this). Trillions of stars suddenly disappear from the infrared sight of the JWT!

A possible explanation for the mysterious disappearance is that the violent collisions of galaxies lead to re-organization of stars and change their observable characteristics so that they effectively disappear. But there are also stars, which look completely stable and then disappear and these are recently studied systematically.

What says TGD?

1. The TGD based explanation for the vanishing stars relies on the prediction that astrophysical objects of various scales, stars, galaxies, etc.. appear as nodes of networks formed from 3-surfaces, which can be thought of as regions of hyperbolic 3-space (cosmic time=constant), which are connected by monopole flux tube pairs.

2. These 3-surfaces form cosmic lattice-like structures, tessellations as they are called by mathematicians [L5]). The connection by flux tube pair is not stable: reconnection (or rather de-reconnection) can occur and lead to a splitting of the pair to two disjoint U-shaped flux tubes assignable to the two originally connected objects. This general mechanism works also outside astrophysics and in the TGD inspired view of quantum biology biocatalysis and biochemical reactions relies on this mechanism.

3. The radiation from stars arrives along the flux tubes connecting astrophysical objects to a network. Diffraction takes place and the signals propagating along the flux tubes are amplified and travel in specific directions only and only between the objects of the network. This applies also to gravitational radiation and could explain the recently observed gravitational hum as being associated with the network of stars.

4. The explanation for the vanishing stars could be very simple: the splitting of the U-shaped flux tube contact between regions containing trillions of stars and Earth, solar system, or even Milky Way. The violent events in the source region could induce these splittings.

6.3 About honeycombs in hyperbolic 3-space

This section, written in 2023, represents some new understanding related to the tessellations of H^3 known as honeycombs.

6.3.1 Some preliminaries

Some preliminaries are needed in order to understand Wikipedia articles related to tessellations in general.

1. Schläfli symbol $\{p,r\}$ (`rb.gy/j36tg`) tells that the possibly existing Platonic solid $\{p,r\}$ has r p-polygons as faces meeting at each vertex. For instance, icosahedron $\{3,5\}$ has 5 triangles as faces meeting at each vertex.

   Schläfli symbol generalizes to higher dimensions. The analog of Platonic solid $\{p,r,q\}$ possibly in 4-dimensions and assignable to 3-sphere has q 3-faces which are Platonic solids $\{p,r\}$. This description is purely combinatorial and is recursive. For instance, one can start from 3-D dimensional Platonic solid $\{p,q\}$ with 3-D objects in dimension 4 by replacing p with p,r. One can also project this object to dimension 3. In this manner one obtains a projection of 4-cube (tesseract) $\{4,3,3\}$ for which 3 cubes $\{4,3\}$ meet at each vertex ($2^4=16$ of them) and which has 8 3-cubes as faces as a 3-D object.

   In the case of hyperbolic tessellations also strange looking Schläfli symbols $\{(p,q,r,s)\}$ are encountered: icosa-tetrahedral tessellation involving only Platonic solids has symbol $\{(3,3,5,3)\}$. My understanding is that this object corresponds to $\{3,3,5,3\}$ as an analogue of Platonic solid associate with 4-sphere in 5-D Euclidian space and that the fundamental region of this tessellation in H^3 is analogous to a 3-D projection of this object. At a given vertex 3 objects $\{3,3,5\}$ meet. For these objects 5 tetrahedrons meet at a given vertex.

2. Vertex figure is a further central notion. It represents a view of the fundamental region of tessellation from a given vertex. The vertices of the figure are connected to this vertex. It does not represent the entire fundamental region. For instance, for a cube (octahedron) it contains only the 3 (4) nearest vertices. For icosa-tetrahedral tessellation the vertex figure is icosidodecahedron (`rb.gy/3u4pq`). The interpretation of the vertex symbol of the hyperbolic icosa-tetrahedral honeycomb (`htrb.gy/3u4pq`) is a considerable challenge.

3. One cannot avoid Coxeter groups and Coxeter symbols (`rb.gy/48qhg`) in the context of tessellations. They code the structure of the symmetry group of say Platonic solid (tessellation of S^2). This symmetry group is generated by reflections with respect to some set of lines, usually going through origin. For regular polygons and Platonic solids is its discrete subgroup of rotation group.

   The Coxeter group is characterized by the number of reflection hyperplanes H_i and the reflections satisfying $r_i^2=1$. The products $r_{ij}=r_ir_j$ define cyclic subgroups of order c_{ij}

satisfying $r_{ij}^{c_{ij}} = 1$. Coxeter group is characterized by a diagram in which vertices are labelled by i. The orders of the cyclic subgroups satisfy $c_{ij} \geq 3$. For c_{ij} the generators r_i and r_{ij} commute. For $c_{ij} = 2$ the vertices are not connected, for $c_{ij} = 3$ there is a line and for $c_{ij} > 3$ the number c_{ij} is assigned with the line. For instance, hyperbolic tessellations are characterized by 4 reflection hyperplanes.

For instance, for p-polygon the Coxeter group has 2 generators and the cyclic group has order p. For Platonic solids the Coxter group has 3 generators and the orders of cyclic subgroups are 3, 4, or 5. For icosa-tetrahedral tessellation the order is 4.

6.3.2 The most interesting honeycombs in hyperbolic 3-space

H^3 allows an infinite number of tessellations. There are 9 types of honeycombs. This makes 76 uniform hyperbolic honeycombs involving only a single polyhedron (`hrb.gy/rs9h5`).

4 of these honeycomes are *regular*, which means that they have identical regular faces (Platonic solids) and the same numbers of faces around vertices. The following list gives the regular uniform honeycombs and their Schläfli symbols $\{p, q, r\}$ telling that each edge has around it regular polygon $\{p, q\}$ for which each vertex is surrounded by q faces with p vertices.

1. H1: 2 regular forms with Schläfli symbol {5,3,4} (dodecahedron) and {4,3,5} (cube).
2. H2: 1 regular form with Schläfli symbol {3,5,3}(icosahedron)
3. H5: 1 regular form with Schläfli symbol {5,3,5} (dodecahedron).

There is a large number of uniform honeycombs involving several cell types. There exists however a "multicellular" honeycomb, which is completely unique in the sense that for it all cells are Platonic solids. This icosa-tetrahedral (or more officially, tetrahedral-icosahedral) honeycomb has tetrahedrons, octahedrons, and icosahedrons as its cells. All faces are triangles. The icosa-tetrahedral honeycomb is of special interest since it might make possible the proposed icosa-tetrahedral realization of the genetic code (`rb.gy/h8xx0`).

From the Wikipedia article about icosa-tetrahedral honeycomb (`htrb.gy/3u4pq`) one learns the following.

1. The Schläfli symbol of icosa-tetrahedral honeycomb is $\{(3, 3, 5, 3)\}$. This combinatorial symbol allows several geometric representations. The inner brackets would refer to the interpretation as an analogue of the Platonic solid assignable to a 4-sphere of Euclidian 5-space. At each vertex 3 objects of type $\{3, 3, 5\}$ would meet. At the vertex of $\{(3, 3, 5)\}$ in turn 5 tetrahedrons meet.
2. Icosa-tetrahedral honeycomb involves tetrahedron $\{(3, 3\}$, octahedron $\{(3, 4)\}$, an icosahedron $\{(3, 5)\}$ as cells. That there are no other honeycombs involving several Platonic solids and only them as cells makes this particular honeycomb especially interesting. Octahedron with Schläfli symbol $\{3, 4\}$ can be also regarded as a rectified tetrahedron havig Schläfli symbol $r\{3, 3\}$.
3. The vertex figure of icosa-tetrahedral honeycomb (`htrb.gy/3u4pq`), representing the vertices a lines connecting them is icosidodecahedron (`rb.gy/q5w62`), which is a "fusion" of icosahedron and dodecahedron having 30 vertices with 2 pentagons and 2 triangles meeting at each, and 60 identical edges, each separating a triangle from pentagon. From a given vertex VF=60 vertices connected to this vertex by an edge can be seen. In the case of cube, octahedron, and dodecahedron the total number of vertices in the polyhedron is 2(VF+1). It is true also now, one would have 122 vertices in the basic structural unit. The total number of vertices for the disjoint polyhedra is 6+4+12= 22 and since vertices are shared, the number of polyhedra in the basic unit must be rather large.
4. The numbers called "cells by location" could correspond to numbers 30, 20, and 12 for octahedrons, tetrahedrons and icosahedrons respectively inside the fundamental region of

the tessellation defining the honeycomb. That the number of icosahedrons is smallest, looks natural. These numbers are quite large. The counts around each vertex are given by (3.3.3.3), (3.3.3), *resp.* (3.3.3.3) for octahedra, tetrahedra, *resp.* icosahedra and tell the numbers of vertices of the faces meeting at a given vertex.

5. What looks intriguing is that the numbers 30, 20, and 12 for octahedrons (O), tetrahedrons (T) and icosahedrons (I) correspond to the numbers of vertices, faces, and edges for I. As if the fundamental region would be obtained by taking an icosahedron and replacing its 30 vertices with O, its 20 faces with T and its 12 edges with I, that is by using the rules *vertex* $\rightarrow$ *octahedron*; *edge* $\rightarrow$ *I*, *face* $\rightarrow$ *T*. These 3-D objects would be fitted together along their triangular faces.

   Do the statements about the geometry and homology of I translate to the statements about the geometry and homology of the fundamental region? This would mean the following replacements:

   (a) "2 faces meet at edge" $\rightarrow$ "2 T:s share face with an I".
   (b) "5 faces meet at vertex" $\rightarrow$ "5 T:s share face with an O".
   (c) "Edge has 2 vertices as ends" $\rightarrow$ "I shares a face with 2 different O:s".
   (d) "Face has 3 vertices $\rightarrow$ "T shares a face with 3 different O:s".
   (e) "Face has three edges" $\rightarrow$ "T has a common face with 3 I:s".

6.3.3 An attempt to understand the hyperbolic honeycombs

The following general observations might help to gain some understanding of the honeycombs.

The tessellations of E^3 and H^3 are in many respects analogous to Platonic solids as 2-D objects. The non-compactness implies that there is an infinite number of cells for tessellations. It is important to notice that the radial coordinate r for H^3 corresponds very closely to the hyperbolic angle and its values are quantized for the vertices of tessellation just like the values of spherical coordinates are quantized for Platonic solids. The tessellations for E^3 are scale covariant. For a fixed radius of H^3 characterized by Lorentz invariance cosmic time this is not the case. One can however scale the value of a. What distinguishes between regular tessellations in E^3 and H^3 is that the metric of H^3 is non-flat and has negative curvature. H^3 is homogeneous space meaning that all points are metrically equivalent (this is the counterpart of cosmological principle in cosmology). Since both spaces have rotations as symmetries, this does not affect basic Platonic solids as 2-D structures assignable with 2-sphere if the edges are identified as geodesic lines of S^2. Quite generally, isometries characterize the tessellations, whose fundamental region corresponds to coset space of H^3/Γ by a discrete group of the Lorentz group acting as isometries of H^3. The modifications induced by the replacement $E^3 \rightarrow H^3$ relate to the 3-D aspects of the tessellation. This is because the metric is non-flat in the radial direction. The negative curvature implies that the geodesic lines diverge. One can use a counterpart of the standard spherical coordinates and in these coordinates the solid angles assignable to the vertices of Platonic solid are smaller than in E^3. Also the hyperbolic planes H^2 emerging from edges of the tessellation of H^3 diverge in normal direction the angles involved are smaller.

It is useful to start from the description of the Platonic solids. They are characterized combinatorially by integers and geometrically by various kinds of angles. Denote by p the number of vertices/edges of the face and by q the number of faces meeting at vertex.

3. Important constraints come from the topology and combinatorics. Basic equations for the numbers V ,E, and F for the number of vertices, edges and faces are purely topological equations $VE+F=2$, and the equation $pF=2E=qV$. Manipulation of these equations gives $1/r+1/p=1/2+1/E$ implying $1/r+1/p>1/2$. Since p and q must be at least 3, the only possibilities for $\{p,q\}$ are $\{3,3\}$, $\{4,3\}$, $\{3,4\}$, $\{5,3\}$, and $\{3,5\}$.

2. The angular positions of the vertices at S^2 are basic angle variables. In H^3 hyperbolic angle assignable to the radial coordinate is an additional variable of this kind analogous to the position of the unit cell in the E^3 tessellation. The cosmological interpretation is in terms of redshift.

3. There is the Euclidian angle ϕ associated with the vertex of the face given by π/p. Here there is no difference between E^3 and H^3.

4. The angle deficit δ associated with the faces meeting at a given vertex due to the fact that the faces are not in plane in which case the total angle would be 2π. δ is largest for tetrahedron with 3 faces meeting at vertex and therefore with the sharpest vertex and smallest for icosahedron with 5 triangles meeting at vertex. This notion is essentially 3-dimensional, being defined using radial geodesics, so that the δ is not the same in H^3. In H^3 δ is expected to be larger than in E^3.

5. There is also the dihedral angle θ associated with the faces as planes of E^3 meeting at the edges of the Platonic solid. θ is smallest for a tetrahedron with 4 edges and largest for a dodecahedron with 20 edges so that the dodecahedron is not far from the flat plane and this angle is not far from π. The H^3 counterpart of θ is associated faces identified as hyperbolic planes H^2 and is therefore different.

6. There is also the vertex solid angle Ω associated with each vertex of the Platonic solid $\{p, q\}$ given by $\Omega = q\theta - (q-2)\pi$. For tessellations in E^3 the sum of these angles is 4π. In H^3 its Euclidian counterpart is larger than 4π.

7. The face solid angle is the solid angle associated with the face when seen from the center of the Platonic solid. The sum of the face solid angles is 4π. For Platonic solid with n vertices, one has $\Omega = 4\pi/n$. The divergence of the geodesics of H^3 implies that this angle is smaller in H^3: there is more volume in H^3 than in E^3.

E^3 allows only single regular tessellation having cube as a unit cell. H^3 allows cubic and icosahedral tessellations plus two tessellations having a dodecahedron as a unit cell. Why does E^3 not allow icosahedral and dodecahedral tessellations and how the curvature of H^3 makes them possible? Why is the purely Platonic tetra-icosahedral tessellation possible in H^3?

The first guess is that these tessellations are almost but not quite possible in E^3 by looking at the Euclidian constraints on various angles. In particular, the sum of dihedral angles θ between faces should be 2π in E^3, the sum of the vertex solid angles Ω at the vertex should be 4π. Note that the scaling of the radial coordinate r decreases the dihedral angles θ and solid angles Ω. This flexibility is expected to make possible so many tessellations and honeycombs in H^3. The larger the deviation of the almost allowed tessellation, the larger the size of the fundamental region for fixed a.

Consider now the constraints on the basic parameters of the Platonic solids (`rb.gy/1cuav`) in E^3 while keeping their H^3 counterparts in mind.

1. The values of didedral angle for tetrahedron, cube, octahedron, dodecahedron, and icosahedron are

$$[\theta(T), \theta(C), \theta(O), \theta(D), \theta(I)] \approx [70.3^\circ,\ 90^\circ, 109.47^\circ,\ 116.57^\circ, 138.19^\circ]\ .$$

   Note that $r = 5$ tetrahedra meeting at a single edge in E^3 would almost fill the space around the edge. In E^3 $r = 4$ cubes can meet at the edge. In H^3 r should be larger. This is indeed the case for the cubic honeycomb $\{4, 3, 5\}$ having $r = 5$. For $r = 3$ icosahedrons the sum dihedral angles exceeds 2π which conforms with the that $\{3, 5, 3\}$ defines an icosahedral tessellation in H^3. For the $r = 4$ dodecahedra meeting at the edge the total dihedral angle is larger than 360°: $r = 4$ is therefore a natural candidate in H^3. There are indeed regular dodecahedral honeycombs with Schläfli symbol $\{5, 3, r\}$, $r = 4$ and $r = 5$. Therefore it seems that the intuitive picture is correct.

2. The values of the vertex solid angle Ω for cube, dodecahedron, and icosahedron are given by the formula $\Omega = q\theta - (q-2)\pi$ giving

$$[\Omega(C), \Omega(D), \Omega(I)] \approx [1.57080, 2.96174, 2.63455].$$

The sum of these angles should be 4π for a tessellation in E^3. In E^3 This is true only for 8 cubes per vertex $(\Omega = \pi/2)$ so that the cubic honeycomb is the only Platonic honeycomb in E^3. The minimal number of cubes per vertex is 9 in H^3. It is convenient to write the values of the vertex solid angles for D and I as

$$[\Omega(D), \Omega(I)] = [0.108174,\ 0.209651] \times 4\pi \ .$$

The number of D:s *resp.* I:s must be at least 10 *resp.* 5 for dodecahedral *resp.* icosahedral honeycombs in H^3.

3. The basic geometric scales of the Platonic solids are circumradius R, surface area A and volume V. The circumradius is given by $R = (a/2)\tan(\pi/q)\tan(\theta/2)$, where a denotes the edge length. The surface area A of the Platonic solid $\{p,q\}$ equals the area of face multiplied by the number F of faces: $A = (a/2)^2 Fpcot(\pi/p)$. The volume V of the Platonic time is F times the volume of the pyramid whose height is the length a of the face: that is $V = FaA/3$.

Choosing $a/2$ as the length unit, the circumradii R , total face areas A an the volumes V of the Platonic solids are given by

$$[R(T), R(C), R(O), R(D), R(I)] = [\sqrt{3}/2, \sqrt{3}, \sqrt{2}, \sqrt{3}\phi, \sqrt{3-\phi}\phi] \ ,$$

$$[A(T), A(C), A(O), A(D), A(I)] = [4\sqrt{3}, 24, 2\sqrt{3}, 12\sqrt{25+10\sqrt{5}}, 20\sqrt{3}] \ ,$$

and

$$[V(T), V(C), V(O), V(D), V(I)] \approx [\sqrt{8}/3, 8,\ \sqrt{128}/3,\ 20\phi^3/(3-\phi), 20\phi^2/3]$$
$$\approx [.942809, 8, 3.771236, 61.304952, 17.453560] \ .$$

What can one say about icosa-tetrahedral tessellation?

1. Consider first the dihedral angles θ. The values of dihedral angles associated T, O, and I in H^3 are reduced from that in E^3 so that their sum in E^2 scene must be larger than 2π. Therefore at least one of these cells must appear twice in H^3. It could be T but also O can be considered. For $2T+O+I$ and $T+2O+I$ the sum would be $388.26°$ *resp.* $427.43°$ in E^3. $2T+O+I$ *resp.* $T+2O+I$could correspond to 4 cells ordered cyclically as ITOT resp. IOTO.

2. The values of the vertex solid angle Ω for tetrahedron, octahedron, and icosahedron are given by $[\Omega(T), \Omega(O), \Omega(I)] = [0.043870, 0.108174, 0.209651]4\pi$ If the numbers of T, O and I are $[n(T), n(O), n(I)]$, one must have $[n(T)\Omega(T), +n(O)\Omega(O) + n(I)\Omega(I) > 4\pi$ in H^3.

If the number of the cells for the fundamental domain are really $[N(T), N(O), N(I)] = [30, 20, 12]$, the first guess is that $[n(T), n(O), n(I)] \propto [N(T), N(O), N(I)$ is approximately true. For $[n(T), n(O), n(I)] = [2,3,1]n(I)$, one obtains $\Omega = n(T)\Omega(T) + n(O)\Omega(O) + n(I)\Omega(I) = n(I) \times .629 \times 4\pi$. This would suggest $n(I) = 2$ giving $[n(T), n(O), n(I)] = [4, 6, 2]$

6.4 Trillions of stars mysteriously disappearing from the sight of James Webb Telescope!

James Webb Telescope is revolutionizing our world view. Now it tells about disappearing stars (see this). Trillions of stars suddenly disappear from the infrared sight of the JWT! This gives support for the vision that astrophysical objects form networks with communications based on radition propagating along the flux tube connections.

A possible standard physics explanation for the mysterious disappearance is that the violent collisions of galaxies lead to re-organization of stars and change their observable characteristics so that they effectively disappear. But there are also stars, which look completely stable and then disappear and these are recently studied systematically.

It is rather easy to guess what the TGD based explanation could be.

1. The TGD based explanation for the vanishing stars relies on the prediction that astrophysical objects of various scales, stars, galaxies, etc.. appear as nodes of networks formed from 3-surfaces, which can be thought of as regions of hyperbolic 3-space (cosmic time=constant), which are connected by monopole flux tube pairs.

2. These 3-surfaces form cosmic lattice-like structures, tessellations as they are called by mathematicians [L5]). The connection by flux tube pair is not stable: reconnection (or rather de-reconnection) can occur and lead to a splitting of the pair to two disjoint U-shaped flux tubes assignable to the two originally connected objects. This general mechanism works also outside astrophysics and in the TGD inspired view of quantum biology biocatalysis and biochemical reactions relies on this mechanism.

3. The radiation from stars arrives along the flux tubes connecting astrophysical objects to a network. Diffraction takes place and the signals propagating along the flux tubes are amplified and travel in specific directions only and only between the objects of the network. This applies also to gravitational radiation and could explain the recently observed gravitational hum as being associated with the network of stars.

4. The explanation for the vanishing stars could be very simple: the splitting of the U-shaped flux tube contact between regions containing trillions of stars and Earth, solar system, or even Milky Way. The violent events in the source region could induce these splittings.

7 Piece-Wise Accelerated Cosmic Expansion As Basic Prediction Of Quantum Cosmology

Quantum cosmology predicts that astrophysical objects do not follow cosmic expansion except in jerk-wise quantum leaps increasing the value of the gravitational Planck constant. This assumption provides explanation for the apparent cosmological constant. Also planets are predicted to expand in this manner. This provides a new version of Expanding Earth theory originally postulated to explain the intriguing findings suggesting that continents have once formed a connected continent covering the entire surface of Earth but with radius which was one half of the recent one.

7.1 Experimental Evidence For Accelerated Expansion Is Consistent With TGD Based Model

There are several pieces of evidence for accelerated expansion, which need not mean cosmological constant, although this is the interpretation adopted in [E11, E4]. It is interesting to see whether this evidence is indeed consistent with TGD based interpretation.

7.1.1 The four pieces of evidence for accelerated expansion

1. Supernovas of type Ia

Supernovas of type Ia define standard candles since their luminosity varies in an oscillatory manner and the period is proportional to the luminosity. The period gives luminosity and from this the distance can be deduced by using Hubble's law: $d = cz/H_0$, H_0 Hubble's constant. The observation was that the farther the supernova was the more dimmer it was as it should have been. In other words, Hubble's constant increased with distance and the cosmic expansion was accelerating rather than decelerating as predicted by the standard matter dominated and radiation dominated cosmologies.

2. Mass density is critical and 3-space is flat

It is known that the contribution of ordinary and dark matter explaining the constant velocity of distance stars rotating around galaxy is about 25 per cent from the critical density. Could it be that total mass density is critical?

From the anisotropy of cosmic microwave background one can deduce that this is the case. What criticality means geometrically is that 3-space defined as surface with constant value of cosmic time is flat. This reflects in the spectrum of microwave radiation. The spots representing small anisotropies in the microwave background temperature is 1 degree and this correspond to flat 3-space. If one had dark matter instead of dark energy the size of spot would be.5 degrees!

Thus in a cosmology based on general relativity cosmological constant remains the only viable option. The situation is different in TGD based quantum cosmology based on sub-manifold gravity and hierarchy of gravitational Planck constants.

3. The energy density of vacuum is constant in the size scale of big voids

It was observed that the density of dark energy would be constant in the scale of 10^8 light years. This length scale corresponds to the size of big voids containing galaxies at their boundaries.

4. Integrated Sachs-Wolf effect

Also so called integrated Integrated Sachs-Wolf effect supports accelerated expansion. Very slow variations of mass density are considered. These correspond to gravitational potentials. Cosmic expansion tends to flatten them but mass accretion to form structures compensates this effect so that gravitational potentials are unaffected and there is no effect of CMB. Situation changes if dark matter is replaced with dark energy the accelerated expansion flattening the gravitational potentials wins the tendency of mass accretion to make them deeper. Hence if photon passes by an over-dense region, it receives a little energy. Similarly, photon loses energy when passign by an under-dense region. This effect has been observed.

7.1.2 Comparison with TGD

The minimum TGD based explanation for accelerated expansion involves only the fact that the embeddings of critical cosmologies correspond to accelerated expansion. A more detailed model allows to understand why the critical cosmology appears during some periods.

1. Accelerated expansion in classical TGD

The first observation is that critical cosmologies (flat 3-space) imbeddable to 8-D embedding space H correspond to negative pressure cosmologies and thus to accelerating expansion. The negativity of the counterpart of pressure in Einstein tensor is due to the fact that space-time sheet is forced to be a 4-D surface in 8-D embedding space. This condition is analogous to a force forcing a particle at the surface of 2-sphere and gives rise to what could be called constraint force. Gravitation in TGD is sub-manifold gravitation whereas in GRT it is manifold gravitation. This would be minimum interpretation involving no assumptions about what mechanism gives rise to the critical periods.

2. Accelerated expansion and hierarchy of Planck constants

One can go one step further and introduce the hierarchy of Planck constants. The basic difference between TGD and GRT based cosmologies is that TGD cosmology is quantum cosmology. Smooth cosmic expansion is replaced by an expansion occurring in discrete jerks corresponding to the increase of gravitational Planck constant. At space-time level this means the replacement of 8-D embedding space H with a book like structure containing almost-copies of H with various values of Planck constant as pages glued together along critical manifold through which space-time sheet can leak between sectors with different values of $\hbar$. This process is the geometric correlate for the phase transition changing the value of Planck constant.

During these phase transition periods critical cosmology applies and predicts automatically accelerated expansion. Neither genuine negative pressure due to "quintessence" nor cosmological constant is needed. Note that quantum criticality replaces inflationary cosmology and predicts a unique cosmology apart from single parameter. Criticality also explains the fluctuations in microwave temperature as long range fluctuations characterizing criticality.

3. Accelerated expansion and flatness of 3-cosmology

Observations 1) and 2) about super-novae and critical cosmology (flat 3-space) are consistent with this cosmology. In TGD dark energy must be replaced with dark matter because the mass density is critical during the phase transition. This does not lead to wrong sized spots since it is the increase of Planck constant which induces the accelerated expansion understandable also as a constraint force due to embedding to H.

4. The size of large voids is the characteristic scale

The TGD based model in its simplest form model assigns the critical periods of expansion to large voids of size 10^8 ly. Also larger and smaller regions can express similar periods and dark space-time sheets are expected to obey same universal "cosmology" apart from a parameter characterizing the duration of the phase transition. Observation 3) that just this length scale defines the scale below which dark energy density is constant is consistent with TGD based model.

The basic prediction is jerk-wise cosmic expansion with jerks analogous to quantum transitions between states of atom increasing the size of atom. The discovery of large voids with size of order 10^8 ly but age much longer than the age of galactic large voids conforms with this prediction. One the other hand, it is known that the size of galactic clusters has not remained constant in very long time scale so that jerk-wise expansion indeed seems to occur.

5. Do cosmic strings with negative gravitational mass cause the phase transition inducing accelerated expansion

Quantum classical correspondence is the basic principle of quantum TGD and suggest that the effective antigravity manifested by accelerated expansion might have some kind of concrete space-time correlate. A possible correlate is super heavy cosmic string like objects at the center of large voids which have negative gravitational mass under very general assumptions. The repulsive gravitational force created by these objects would drive galaxies to the boundaries of large voids. At some state the pressure of galaxies would become too strong and induce a quantum phase transition forcing the increase of gravitational Planck constant and expansion of the void taking place much faster than the outward drift of the galaxies. This process would repeat itself. In the average sense the cosmic expansion would not be accelerating.

7.1.3 Does TGD allow description of accelerated expansion in terms of cosmological constant?

The introduction of cosmological constant seems to be the only manner to explain accelerated expansion and related effects in the framework of General Relativity. TGD allows different explanation of these effects. It is however interesting to look whether TGD allows a description based on finite cosmological constant as a small deformation of De Sitter space represented as a vacuum extremal. Before this a clarifying comment about the term "vacuum energy".

The term vacuum energy density is bad use of language since De Sitter space [B2] is a solution of field equations with cosmological constant at the limit of vanishing energy momentum tensor carries *vacuum curvature* rather than vacuum energy. Thus theories with non-vanishing cosmological constant represent a family of gravitational theories for which vacuum solution is not flat so that Einstein's basic identification matter = curvature is given up. No wonder, Einstein regarded the introduction of cosmological constant as the biggest blunder of his life.

De Sitter space is representable as a hyperboloid $a^2 - u^2 = -R^2$, where one has $a^2 = t^2 - r^2$ and $r^2 = x^2 + y^2 + z^2$. The symmetries of de Sitter space are maximal but Poincare group is replaced with Lorentz group of 5-D Minkowski space and translations are not symmetries. The value of cosmological constant is $\Lambda = 3/R^2$. The presence of non-vanishing dimensional constant is from the point of view of conformal invariance a feature raising strong suspicions about the correctness of the underlying physics.

1. Embeddings of De Sitter space

De Sitter space is possible as a vacuum extremal in TGD framework. There exists infinite number of embeddings as a vacuum extremal into $M^4 \times CP_2$. Take any infinitely long curve X in CP_2 not intersecting itself (one might argue that infinitely long curve is somewhat pathological) and introduce a coordinate u for it such that its induced metric is $ds^2 = du^2$. De Sitter space allows the standard embedding to $M^4 \times X$ as a vacuum extremal. The embedding can be written as $u = \pm[a^2 + R^2]^{1/2}$ so that one has $r^2 < t^2 + R^2$. One example is curve in S^2 which spirals around chosen point infinitely many times so that at the vicinity of point it almost fills 2-dimensional region of S^2. One can also combine spirals associated with two distinct points so that u coordinate spans range $[-\infty, \infty]$.

The curve in question can also fill 2-D or higher-dimensional sub-manifold of CP_2 densely. An example is torus densely filled by the curve $\phi = \alpha\psi$ where α is irrational number. Note that even a slightest local deformation of this object induces an infinite number of self-intersections. Space-time sheet fills densely 5-D set in this case. One can ask whether this kind of objects might be analogs of $D > 4$ branes in TGD framework. As a matter fact, CP_2 projections of 1-D vacuum extremals could give rise to both the analogs of branes and strings connecting them if space-time surface contains both regular and "brany" pieces. Perhaps this might provide a new (possibly) approach to the understanding of branes in M-theory context.

It might be that the 2-D Lagrangian manifolds representing CP_2 projection of the most general vacuum extremal, can fill densely $D > 2$-dimensional sub-manifold of CP_2. One can imagine construction of very complex Lagrange manifolds by gluing together pieces of 2-D Lagrangian sub-manifolds by arbitrary 1-D curves. One could also rotate 2-Lagrangian manifold along a 2-torus - just like one rotates point along 2-torus in the above example - to get a dense filling of 4-D volume of CP_2.

The M^4 projection of the embedding corresponds to the region $a^2 > -R^2$ containing future and past light-cones. If u varies only in range $[0, u_0]$ only hyperboloids with a^2 in the range $[-R^2, -R^2 + u_0^2]$ are present in the foliation. In zero energy ontology the space-like boundaries of this piece of De Sitter space, which must have $u_0^2 > R^2$, would be carriers of positive and negative energy states. The boundary corresponding to $u_0 = 0$ is space-like and analogous to the orbit of partonic 2-surface. For $u_0^2 < R^2$ there are no space-like boundaries and the interpretation as a zero energy state is not possible. Note that the restriction $u_0^2 \geq R^2$ plus the choice of the branch of the embedding corresponding to future or past directed light-cone is natural in TGD framework.

2. Could negative cosmological constant make sense in TGD framework?

The questionable feature of slightly deformed De Sitter metric as a model for the accelerated expansion is that the value of a would be same order of magnitude as the recent age of the Universe. Why should just this value of cosmic time be so special? In TGD framework one could of course consider space-time sheets having De Sitter cosmology characterized by a varying value of R. Also the replacement of one spatial coordinate with CP_2 coordinate implies very strong breaking of translational invariance. Hence the explanation relying on quantization of gravitational Planck constant looks more attractive to me.

It is however always useful to make an exercise in challenging the cherished beliefs.

1. Could the complete failure of the perturbation theory around canonically imbedded M^4 make De Sitter cosmology natural vacuum extremal. De Sitter space appears also in the models of inflation and long range correlations might have something to do with the intersections between distant points of 3-space resulting from very small local deformations. Could both the slightly deformed De Sitter space and quantum critical cosmology represent cosmological epochs in TGD Universe?

2. Gravitational energy defined as a non-conserved Noether charge in terms of Einstein tensor TGD is infinite for de-Sitter cosmology (Λ as characterizer of vacuum energy). If one includes to the gravitational momentum also metric tensor gravitational four-momentum density vanishes (Λ as characterizer of vacuum curvature). TGD does not involve Einstein-Hilbert action as fundamental action and gravitational energy momentum tensor should be

dictated by finiteness condition so that negative cosmological constant might make sense in TGD.

3. The embedding of De Sitter cosmology involves the choice of a preferred light-cone as does also quantization of Planck constant. Quantization of Planck constant involves the replacement of the light-cones of $M^4 \times CP_2$ by its finite coverings and orbifolds glued to together along quantum critical sub-manifold. Finite pieces of De Sitter space are obtained for rational values of α and there is a covering of light-cone by CP_2 points. How can I be sure that there does not exist a deeper connection between the descriptions based on cosmological constant and on phase transitions changing the value Planck constant?

Note that Anti de Sitter space [B1] having similar embedding to 5-D Minkowski space with two time like dimensions does not possess this kind of embedding to H. Very probably no embeddings exist so that TGD would allow only embeddings of cosmologies with correct sign of Λ whereas M-theory in its basic form predicts a wrong sign for it. Note also that Anti de Sitter space appearing in AdS-CFT dualities contains closed time-like loops and is therefore also physically questionable.

7.1.4 The mystery of mini galaxies and the hierarchy of Planck constants

New Scientist [E22] informs that a team led by Pieter van Dokkum at Yale University measured the light of distant galaxies from around 3 billion years after the big bang. They had the same mass as the Milky Way, but were 10 times smaller (The Astrophysical Journal, vol. 677, p. L5). Peering at younger regions of the sky shows that galaxies this size are no longer around, but it's not clear what happened to them. "This is a very puzzling result" says Simon White of the Max Planck Institute for Astrophysics in Garching, Germany. "Galaxies cannot disappear." Team member Marijn Franx of Leiden Observatory, the Netherlands, suspects they have since merged with extremely massive galaxies. The disappearance of the mini galaxies would be due to this mechanism. From the assumption that this mechanism gives rise to the same outcome as smooth expansion within factor of two at given moment, one could estimate their recent size. If the galaxies are assumed to have roughly the size of Milky Way now, an upwards scaling would be roughly by a factor 8. This would mean that recent age of Universe would be about 24 billion years.

7.2 Quantum Version Of Expanding Earth Theory

TGD predicts that cosmic expansion at the level of individual astrophysical systems does not take place continuously as in classical gravitation but through discrete quantum phase transitions increasing gravitational Planck constant and thus various quantum length and time scales. The reason would be that stationary quantum states for dark matter in astrophysical length scales cannot expand. One would have the analog of atomic physics in cosmic scales. Increases of $\hbar$ by a power of two are favored in these transitions but also other scalings are possible.

This has quite far reaching implications.

1. These periods have a highly unique description in terms of a critical cosmology for the expanding space-time sheet. The expansion is accelerating. The accelerating cosmic expansion can be assigned to this kind of phase transition in some length scale (TGD Universe is fractal). There is no need to introduce cosmological constant and dark energy would be actually dark matter.

2. The recently observed void which has same size of about 10^8 light years as large voids having galaxies near their boundaries but having an age which is much higher than that of the large voids, would represent one example of jerk-wise expansion.

3. This picture applies also to solar system and planets might be perhaps seen as having once been parts of a more or less connected system, the primordial Sun. The Bohr orbits for inner and outer planets correspond to gravitational Planck constant which is 5 times larger for outer planets. This suggests that the space-time sheet of outer planets has suffered a phase transition increasing the size scale by a factor of 5. Earth can be regarded either as n=1 orbit for Planck constant associated with outer planets or n= 5 orbit for inner planetary system. This might have something to do with the very special position of Earth in planetary

system. One could even consider the possibility that both orbits are present as dark matter structures. The phase transition would also explain why n=1 and n=2 Bohr orbits are absent and one only n=3, 4, and 5 are present.

4. Also planets should have experienced this kind of phase transitions increasing the radius: the increase by a factor two would be the simplest situation.

The obvious question - that I did not ask - is whether this kind of phase transition might have occurred for Earth and led from a completely granite covered Earth - Pangeia without seas - to the recent Earth. Neither it did not occur to me to check whether there is any support for a rapid expansion of Earth during some period of its history.

Situation changed when my son visited me last Saturday and told me about a Youtube video [F43] by Neal Adams, an American comic book and commercial artist who has also produced animations for geologists. We looked the amazing video a couple of times and I looked it again yesterday. The video is very impressive artwork but in the lack of references skeptic probably cannot avoid the feeling that Neal Adams might use his highly developed animation skills to cheat you. I found also a polemic article [F1] of Adams but again the references were lacking. Perhaps the reason of polemic tone was that the concrete animation models make the expanding Earth hypothesis very convincing but geologists refuse to consider seriously arguments by a layman without a formal academic background.

7.2.1 The claims of Adams

The basic claims of Adams were following.

1. The radius of Earth has increased during last 185 million years (dinosaurs [I2] appeared for about 230 million years ago) by about factor 2. If this is assumed all continents have formed at that time a single super-continent, Pangeia, filling the entire Earth surface rather than only 1/4 of it since the total area would have grown by a factor of 4. The basic argument was that it is very difficult to imagine Earth with 1/4 of surface containing granite and 3/4 covered by basalt. If the initial situation was covering by mere granite -as would look natural- it is very difficult for a believer in thermodynamics to imagine how the granite would have gathered to a single connected continent.

2. Adams claims that Earth has grown by keeping its density constant, rather than expanded, so that the mass of Earth has grown linearly with radius. Gravitational acceleration would have thus doubled and could provide a partial explanation for the disappearance of dinosaurs: it is difficult to cope in evolving environment when you get slower all the time.

3. Most of the sea floor is very young and the areas covered by the youngest basalt are the largest ones. This Adams interprets this by saying that the expansion of Earth is accelerating. The alternative interpretation is that the flow rate of the magma slows down as it recedes from the ridge where it erupts. The upper bound of 185 million years for the age of sea floor requires that the expansion period - if it is already over - lasted about 185 million years after which the flow increasing the area of the sea floor transformed to a convective flow with subduction so that the area is not increasing anymore.

4. The fact that the continents fit together - not only at the Atlantic side - but also at the Pacific side gives strong support for the idea that the entire planet was once covered by the super-continent. After the emergence of subduction theory this evidence as been dismissed.

5. I am not sure whether Adams mentions the following objections [F5]. Subduction only occurs on the other side of the subduction zone so that the other side should show evidence of being much older in the case that oceanic subduction zones are in question. This is definitely not the case. This is explained in plate tectonics as a change of the subduction direction. My explanation would be that by the symmetry of the situation both oceanic plates bend down so that this would represent new type of boundary not assumed in the tectonic plate theory.

6. As a master visualizer Adams notices that Africa and South-America do not actually fit together in absence of expansion unless one assumes that these continents have suffered a deformation. Continents are not easily deformable stuff. The assumption of expansion implies a perfect fit of *all* continents without deformation.

Knowing that the devil is in the details, I must admit that these arguments look rather convincing to me and what I learned from Wikipedia articles supports this picture.

7.2.2 The critic of Adams of the subduction mechanism

The prevailing tectonic plate theory [F26] has been compared to the Copernican revolution in geology. The theory explains the young age of the seafloor in terms of the decomposition of the litosphere to tectonic plates and the convective flow of magma to which oceanic tectonic plates participate. The magma emerges from the crests of the mid ocean ridges representing a boundary of two plates and leads to the expansion of sea floor. The variations of the polarity of Earth's magnetic field coded in sea floor provide a strong support for the hypothesis that magma emerges from the crests.

The flow back to would take place at so called oceanic trenches [F19] near continents which represent the deepest parts of ocean. This process is known as subduction. In subduction oceanic tectonic plate bends and penetrates below the continental tectonic plate, the material in the oceanic plate gets denser and sinks into the magma. In this manner the oceanic tectonic plate suffers a metamorphosis returning back to the magma: everything which comes from Earth's interior returns back. Subduction mechanism explains elegantly formation of mountains [F20] (orogeny), earth quake zones, and associated zones of volcanic activity [F35] .

Adams is very polemic about the notion of subduction, in particular about the assumption that it generates steady convective cycle. The basic objections of Adams against subduction are following.

1. There are not enough subduction zones to allow a steady situation. According to Adams, the situation resembles that for a flow in a tube which becomes narrower. In a steady situation the flow should accelerate as it approaches subduction zones rather than slow down. Subduction zones should be surrounded by large areas of sea floor with constant age. Just the opposite is suggested by the fact that the youngest portion of sea-floor near the ridges is largest. The presence of zones at which both ocean plates bend down could improve the situation. Also jamming of the flow could occur so that the thickness of oceanic plate increases with the distance from the eruption ridge. Jamming could increase also the density of the oceanic plate and thus the effectiveness of subduction.

2. There is no clear evidence that subduction has occurred at other planets. The usual defense is that the presence of sea is essential for the subduction mechanism.

3. One can also wonder what is the mechanism that led to the formation of single super continent Pangeia covering 1/4 of Earth's surface. How probable the gathering of all separate continents to form single cluster is? The later events would suggest that just the opposite should have occurred from the beginning.

7.2.3 Expanding Earth theories are not new

After I had decided to check the claims of Adams, the first thing that I learned is that Expanding Earth theory [F5], whose existence Adams actually mentions, is by no means new. There are actually many of them.

The general reason why these theories were rejected by the main stream community was the absence of a convincing physical mechanism of expansion or of growth in which the density of Earth remains constant.

1. 1888 Yarkovski postulated some sort of aether absorbed by Earth and transforming to chemical elements (TGD version of aether could be dark matter). 1909 Mantovani [F42] postulated thermal expansion but no growth of the Earth's mass.

2. Paul Dirac's idea about changing Planck constant led Pascual Jordan in 1964 to a modification of general relativity predicting slow expansion of planets. The recent measurement of the gravitational constant imply that the upper bound for the relative change of gravitational constant is 10 time too small to produce large enough rate of expansion. Also many other theories have been proposed but they are in general conflict with modern physics.

3. The most modern version of Expanding Earth theory is by Australian geologist Samuel W. Carey. He calculated that in Cambrian period (about 500 million years ago) all continents were stuck together and covered the entire Earth. Deep seas began to evolve then.

7.2.4 Summary of TGD based theory of Expanding Earth

TGD based model differs from the tectonic plate model but allows subduction which cannot imply considerable back-flow of magma. Let us sum up the basic assumptions and implications.

1. The expansion is or was due to a quantum phase transition increasing the value of gravitational Planck constant and forced by the cosmic expansion in the average sense.

2. Tectonic plates do not participate to the expansion and therefore new plate must be formed and the flow of magma from the crests of mid ocean ridges is needed. The decomposition of a single plate covering the entire planet to plates to create the mid ocean ridges is necessary for the generation of new tectonic plate. The decomposition into tectonic plates is thus prediction rather than assumption.

3. The expansion forced the decomposition of Pangeia super-continent covering entire Earth for about 530 million years ago to split into tectonic plates which began to recede as new non-expanding tectonic plate was generated at the ridges creating expanding sea floor. The initiation of the phase transition generated formation of deep seas.

4. The eruption of plasma from the crests of ocean ridges generated oceanic tectonic plates which did not participate to the expansion by density reduction but by growing in size. This led to a reduction of density in the interior of the Earth roughly by a factor 1/8. From the upper bound for the age of the seafloor one can conclude that the period lasted for about 185 million years after which it transformed to convective flow in which the material returned back to the Earth interior. Subduction at continent-ocean floor boundaries and downwards double bending of tectonic plates at the boundaries between two ocean floors were the mechanisms. Thus tectonic plate theory would be more or less the correct description for the recent situation.

5. One can consider the possibility that the subducted tectonic plate does not transform to magma but is fused to the tectonic layer below continent so that it grows to an iceberg like structure. This need not lead to a loss of the successful predictions of plate tectonics explaining the generation of mountains, earthquake zones, zones of volcanic activity, etc...

6. From the video of Adams it becomes clear that the tectonic flow is East-West asymmetric in the sense that the western side is more irregular at large distances from the ocean ridge at the western side. If the magma rotates with slightly lower velocity than the surface of Earth (like liquid in a rotating vessel), the erupting magma would rotate slightly slower than the tectonic plate and asymmetry would be generated.

7. If the planet has not experienced a phase transition increasing the value of Planck constant, there is no need for the decomposition to tectonic plates and one can understand why there is no clear evidence for tectonic plates and subduction in other planets. The conductive flow of magma could occur below this plate and remain invisible.

The biological implications might provide a possibility to test the hypothesis.

1. Great steps of progress in biological evolution are associated with catastrophic geological events generating new evolutionary pressures forcing new solutions to cope in the new situation. Cambrian explosion indeed occurred about 530 years ago (the book "Wonderful Life"

of Stephen Gould [I9] explains this revolution in detail) and led to the emergence of multicellular creatures, and generated huge number of new life forms living in seas. Later most of them suffered extinction: large number of phylae and groups emerged which are not present nowadays.

Thus Cambrian explosion is completely exceptional as compared to all other dramatic events in the evolution in the sense that it created something totally new rather than only making more complex something which already existed. Gould also emphasizes the failure to identify any great change in the environment as a fundamental puzzle of Cambrian explosion. Cambrian explosion is also regarded in many quantum theories of consciousness (including TGD) as a revolution in the evolution of consciousness: for instance, micro-tubuli emerged at this time. The periods of expansion might be necessary for the emergence of multicellular life forms on planets and the fact that they unavoidably occur sooner or later suggests that also life develops unavoidably.

2. TGD predicts a decrease of the surface gravity by a factor 1/4 during this period. The reduction of the surface gravity would have naturally led to the emergence of dinosaurs 230 million years ago as a response coming 45 million years after the accelerated expansion ceased. Other reasons led then to the decline and eventual catastrophic disappearance of the dinosaurs. The reduction of gravity might have had some gradually increasing effects on the shape of organisms also at microscopic level and manifest itself in the evolution of genome during expansion period.

3. A possibly testable prediction following from angular momentum conservation ($\omega R^2 = constant$) is that the duration of day has increased gradually and was four times shorter during the Cambrian era. For instance, genetically coded bio-clocks of simple organisms during the expansion period could have followed the increase of the length of day with certain lag or failed to follow it completely. The simplest known circadian clock is that of the prokaryotic cyanobacteria. Recent research has demonstrated that the circadian clock of Synechococcus elongatus can be reconstituted in vitro with just the three proteins of their central oscillator. This clock has been shown to sustain a 22 hour rhythm over several days upon the addition of ATP: the rhythm is indeed faster than the circadian rhythm. For humans the average innate circadian rhythm is however 24 hours 11 minutes and thus conforms with the fact that human genome has evolved much later than the expansion ceased.

4. Scientists have found a fossil of a sea scorpion with size of 2.5 meters [I6], which has lived for about 10 million years for 400 million years ago in Germany. The gigantic size would conform nicely with the much smaller value of surface gravity at that time. The finding would conform nicely with the much smaller value of surface gravity at that time. Also the emergence of trees could be understood in terms of a gradual growth of the maximum plant size as the surface gravity was reduced. The fact that the oldest known tree fossil is 385 million years old [I7] conforms with this picture.

7.2.5 Did intra-terrestrial life burst to the surface of Earth during Cambrian expansion?

Intra-terrestrial hypothesis [K18] is one of the craziest TGD inspired ideas about the evolution of life and it is quite possible that in its strongest form the hypothesis is unrealistic. One can however try to find what one obtains from the combination of the IT hypothesis with the idea of pre-Cambrian granite Earth. Could the harsh pre-Cambrian conditions have allowed only intra-terrestrial multicellular life? Could the Cambrian explosion correspond to the moment of birth for this life in the very concrete sense that the magma flow brought it into the day-light?

1. Gould emphasizes the mysterious fact that very many life forms of Cambrian explosion looked like final products of a long evolutionary process. Could the eruption of magma from the Earth interior have induced a burst of intra-terrestrial life forms to the Earth's surface? This might make sense: the life forms living at the bottom of sea do not need direct solar light so that they could have had intra-terrestrial origin. It is quite possible that Earth's mantle contained low temperature water pockets, where the complex life forms might have evolved in an environment shielded from meteoric bombardment and UV radiation.

2. Sea water is salty. It is often claimed that the average salt concentration inside cell is that of the primordial sea: I do not know whether this claim can be really justified. If the claim is true, the cellular salt concentration should reflect the salt concentration of the water inside the pockets. The water inside water pockets could have been salty due to the diffusion of the salt from ground but need not have been same as that for the ocean water (higher than for cell interior and for obvious reasons). Indeed, the water in the underground reservoirs in arid regions such as Sahara is salty, which is the reason for why agriculture is absent in these regions. Note also that the cells of marine invertebrates are osmoconformers able to cope with the changing salinity of the environment so that the Cambrian revolutionaries could have survived the change in the salt concentration of environment.

3. What applies to Earth should apply also to other similar planets and Mars [E5] is very similar to Earth. The radius is .533 times that for Earth so that after quantum leap doubling the radius and thus Schumann frequency scale (7.8 Hz would be the lowest Schumann frequency) would be essentially same as for Earth now. Mass is.131 times that for Earth so that surface gravity would be.532 of that for Earth now and would be reduced to.131 meaning quite big dinosaurs! have learned that Mars probably contains large water reservoirs in it's interior and that there is an un-identified source of methane gas usually assigned with the presence of life. Could it be that Mother Mars is pregnant and just waiting for the great quantum leap when it starts to expand and gives rise to a birth of multicellular life forms. Or expressing freely how Bible describes the moment of birth: in the beginning there was only darkness and water and then God said: Let the light come!

To sum up, TGD would not only provide the long sought mechanism of expansion of Earth but also a possible connection with the biological evolution. It would be indeed fascinating if Planck constant changing quantum phase transitions in planetary scale would have profoundly affected the biosphere.

8 Implications Of Expanding Earth Model For The Pre-Cambrian Evolution Of Continents, Of Climate, And Of Life

Expanding Earth hypothesis is by no means not new. It was proposed by Mantovani and I learned about it from the video animations of [F43, F1] demonstrating that the continents fit nicely to form a single continent covering entire Earth if the radius is one half of the recent radius. What TGD has to give is a new physics justification for Expanding Earth hypothesis: cosmic expansion is replaced with a sequence of fast expansion periods increasing the value of Planck constant and these transitions occur in all scales.

If Expanding Earth hypothesis is correct it forces to modify dramatically the view about pre-Cambrian period. The super-continent theory could be replaced by much simpler theory and it might be possible to give up the assumption about hypothetical super continents and super oceans. The view about glaciations [F7] must be modified dramatically. Concerning the evolution of life the natural hypothesis is that it escaped to the underground seas formed as a consequence of expansion during pre-Cambrian era and returned back to the surface in Cambrian Explosion. In this section super-continent and super-ocean theory is discussed from TGD point of view. A model for glaciations based on the assumption that the radius of Earth was in good approximation one half of the recent radius during pre-Cambrian era is developed and shown to reduce to a sequence of ordinary glaciations initiated at pole caps. Snowball theory serves as a convenient reference. Expanding Earth theory is discussed also from paleomagnetic point of view and some experimental signatures of $R/2$ scenario differentiating it from standard scenarios are developed. Finally the hypothesis about underground evolution is discussed.

8.1 Super-Continent Theory

Super-continent theory assumes a cyclic formation of hypothetical super continents [F30]. Rodinia [F28], Pannotia [F24], and Pangea [F23] might have preceded by earlier super-continents. The period would be roughly 250 Myr.

1. The super-continent Rodinia [F28] is assumed to have existed during interval: 1100-750 Myr. 750 Myr ago Rodinia rifted into three continents: Proto-Laurasia which broke up and eventually reformed to form Laurasia (North America and Asia), the continental craton of Congo (part of Africa), and Gondwana (now southern hemisphere plus India).

2. Pannotia [F24] existed during time interval 600-540 Myr. Pannotia rifted in the beginning of Cambrian era to Laurentia (North America), Baltica, Siberia and Gondwana. See the illustration of Pannotia at [F13].

3. Wegener [F2] ended up to postulate that super-continent Pangea should have existed about 250 Myr ago [F23]. The support for its existence is rather strong since tectonic plate model and paleo-magnetic methods allows to trace the drift of the tectonic plates.

One can criticize the cyclic model. The concentration of land mass to Southern Hemisphere during Rodinia period does not look very probable event. The cyclically occurring formation of connected land mass surrounded by much larger ocean looks even less probable unless one can develop some very good physical mechanism forcing this. The basic motivation for super-continent theory are various correlations between distant parts of Earth which would cannot be understood otherwise. In $R/2$ model the continents would have been quite near to each other during the expansion and the notion of cyclic formation of super-continents becomes un-necessary since land bridges between the continents could explain the correlations. There would have been just single super-continent all the time.

8.2 Standard View About Oceans

In the standard model the total area covered by oceans has reduced since pre-Cambrian era due to the increase of the continental cover, which is nowadays 29 per cent. Oceans cover the remaining 71 per cent with Antarctica and Arctica included. The evolution of Oceans in standard model requires the introduction of hypothetical oceans which left no trace about their existence (subduction mechanism provides perhaps too convenient trash bin for hypothetical theoretical constructs).

1. Proto-Atlantic Ocean was introduced to explain some contradictions with Wegener's Pangea model allowing to conclude which parts at opposite sides of Atlantic Ocean had been in contact. Proto-Atlantic Ocean closed as Pangea formed and opened again in slightly different manner to form Atlantic Ocean. This process implied mixing of older pieces of the continents and explained the contradictions. Large inland sea is a natural counterpart of the Proto-Atlantic Ocean in $R/2$ option.

2. Mirovia [F17] was the super-ocean surrounding Rodinia. It transformed to Pan-African Ocean surrounding Pannotia. Pan-African ocean was then closed so that the ocean floor of Mirovia disappeared by subduction and left no signs about its existence.

3. In the rifting [F27] of Pannotia Panthalassic ocean [F25] emerged and was the precedessor of the Pacific ocean.

The presence of super-oceans is forced by the assumption that the radius of Earth was the recent one during the pre-Cambrian era plus the local data related to the evolution of continents. The questionable aspect is that these oceans did not leave any direct trace about their existence. In $R/2$ model there is no need for these super-oceans except possibly the counterpart of Panthalassic Ocean [F25].

8.3 Glaciations During Neoproterozoic Period

Glaciations dominated the Neoproterozoic period [F18] between 1-.542 billion years. The period is divided into Tonian [F34], Cryogenian [F3], and Ediacaran periods [F4]. The most severe glaciations occurred during Cryogenian period.

It is believed that during Cryogenian period [F3] two worldwide glaciations -Sturtian and Marinoan glaciations- took place. This involves extrapolation of continental drift model and plate tectonics theory. Also hypothesis about hypothetical super-continents is needed so that one must take these beliefs with some skepticism. In $R/2$ model the world wide glaciations are replaced with ordinary glaciations proceeding from poles.

1. Sturtian glaciation occurred 750-700 Myr. The breakup of Rodinia is believed to have occurred at this time. One can wonder whether there is a correlation between these events. $R/2$ model suggest that the energy needed to compensate the reduction of gravitational energy in expansion could have caused the cooling.

2. Marinoan (Varanger) glaciation ended around 635 Myr ago.

Deposits of glacial tillites [F32] at low latitudes serve as support for the claim that these glaciations were world wide. In $R/2$ model Equator corresponds to North pole in TGD framework where Rodinia covered entire Earth and the interpretation would as ordinary glaciations.

After the end of Marinoan glaciation followed Ediacaran period during 635-542 Myr [F4]. The first multicellular fossils appeared at this time. Their relationship to Cambrian fossils is unclear. The standard interpretation for the small number of fossils in pre-Cambrian period is that hard shells needed for fossilization were not yet developed. The problem is that these shells should have developed almost instantaneously in Cambrian explosion.

8.4 Snowball Earth Model For The Glaciation During Pre-Cambrian Era

Snowball Earth [F41, F36, F29] is recently the leading model for the glaciations [F8] during Proterozoic era. The term is actually somewhat misleading: Iceball Earth would more to the point. Slushball earth [F38] is a variant of Snowball Earth which does not assume total freezing near equator.

The history behind the Snowball Earth concept is roughly following [F29].

1. Mawson studied the Neoproterozoic stratigraphy of South Australia and identified extensive glacial sediments and speculated with the possibility of global glaciation. He did not know anything about continental drift hypothesis and plate tectonic theory and thought that the ancient position of Australia was the same as it is today. Continent drifting hypothesis however explained the finding as sediments deposited at the higher latitudes the hypothesis was forgotten.

2. Later Harland suggested on basis of geomagnetic data that glacial tillites [F32] in Svalbard and Greenland were deposited at tropical latitudes. In TGD framework with with $R \to R/2$ these tillites would have been at higher latitudes towards North Pole.

3. The facts are that Sun was 6 per cent fainter at that time and glaciations are known to occur. The question is whether they were global and long-lasting or a sequence of short-lasting possibly local glaciations. The Russian climatologist Budyko constructed a model based on energy balance and found that it is possible to have a global glaciation if the ice sheets proceeded enough from polar regions (to about 30 degree latitude). The model was based on the increased reflectiveness (albedo) of the Earth's surface due to the ice covering giving rise to positive feedback loop. Budyko did not believe that global glaciation had occurred since the model offered no way to escape eternal glaciation.

4. Kirschwink introduced the term Snowball Earth, which is actually misleading. Iceball Earth would be more to the point. He found that the so called banded iron formations are consistent with a global glaciation. He also proposed a mechanism for melting the snowball. The accumulation of CO_2 from volcanoes would have caused ultra-greenhouse effect causing warming of the atmosphere and melting of the ice.

5. Slushball Earth [F38] differs from Snowball Earth in that only a thin ice cover or even its absence near equator is assumed. The model allows to explain various findings in conflict with Snowball Earth, such as the evidence for the presence of melt-water basins.

6. Zipper rift model [F37] assumes that there was a sequence of glaciations rather similar to the glaciations that have occurred later. The model assumes that the rifts [F27] of the super-continent Rodinia occurred simultaneously with glaciations. The associated tectonic uplift led to the formation of high plateaus hosting the glaciers. The iron band formation can be assigned with inland seas allowing complex chemistries and anoxicity near the sea floor.

8.4.1 The basic ideas of the Snowball Earth model

Snowball Earth [F41, F36, F29] differs from ordinary glaciations in that only oceans are frozen whereas in the ordinary glaciation land mass is covered by ice. The basic ideas of the snowball Earth relate to the mechanism initiating the global freezing and melting.

1. The glaciation would have been initiated by some event, say a creation of super-volcano. Also astrophysical mechanism might be involved. Somewhat paradoxically, tropical continents during cryogenian period [F3] are needed for the initiation because they reflect the solar radiation more effectively than tropical oceans.

2. The positive ice-albedo feedback is an essential concept: the more ice the larger the fraction of the radiation reflected back so that the more ice is generated. If the glaciation proceeds over a critical latitude about 30 degrees positive feedback forces a global glaciation.

3. The problem of the model is how to get rid of the glaciation. The proposal of Kirschvink was that the accumulation of CO_2 from volcanoes could have led to a global super-warming. The time scale for CO_2 emissions is measured in millions of years. The needed atmospheric concentration of CO_2 is by a factor 350 higher than the recent concentration. Due the ice cover the CO_2 could not be absorbed to the siliceous rocks and concentration would increase. The melting of the ice meant higher absorbtion of heat by uncovered land. Positive feedback loop was at work again but in different direction.

8.4.2 Evidence for and objections against Snowball Earth

Wikipedia article about Snowball Earth [F29] discusses both evidence for and objections against Snowball Earth. Low latitude sediments at tropical latitudes and tropical tillites at Equatorial latitudes provide strong piece of evidence for Snowball Earth. Calcium carbonate deposits having ^{13}C signature (per cent for the depletion of ^{13} isotope and large for organic material) consistent with that for mantle meaning abiotic origin is second evidence. Iridium anomaly located at the base of Calcium Carbonate deposits is third piece of evidence. The evidence for Snowball Earth will be discussed in more detail later since it is convenient to relate the evidence to $R/2$ model for glaciations.

1. Paleomagnetic data [F22] used to the dating of sediments assuming tectonic plane theory and super-continent drifting might be misleading. No pole wandering maps exist and the polarity of the magnetic field must be deduced by statistical methods. The primary magnetization could have been reset and the orientation of the magnetic minerals could have changed from the original one. It is also possible that magnetic field patterns were not dipolar. Also the assumption of hypothetical super-continents and oceans brings in uncertainties. In $R/2$ model of course the determination of the positions changes completely.

2. Carbon isotope ratios are not what they should be. There are rapid variations of $^{12}C/^{13}C$ ratio with organic origin. Suggests that freezing and melting followed each other in rapid succession. In standard framework this would suggest Slushball Earth meaning ice-free and ice-thin regions around the equator and hydrological cycles. In $R/2$ model the regions at Equator are near North Pole and the explanation would be in terms of ordinary glaciations.

3. The distribution of isotopes of element Boron suggest variations of pH of oceans. The explanation is in terms of buildup of carbon dioxide in atmosphere dissolved into oceans/seas. In $R/2$ model a sequence of glaciations would explain the findings.

4. Banded iron formations providing support for the model are actually rather rare and absent during Marinoan glaciation.

5. Wave-formed ripples, far-traveled ice-rafted debris and indicators of photosynthetic activity, can be found throughout sediments dating from the "Snowball Earth" periods. This serves a evidence open-water deposits. In snow-ball model these could be "oases" of melt-water but computer simulations suggest that large areas of oceans would have left ice-free. in $R/2$ model these would be signatures of ordinary glaciations.

6. Paleomagnetic data have led to the conclusion that Australia was at Equator. In $R/2$ model it would have been near North Pole. Namibia was also thought to be near Equator [F31]. Indirect arguments forced the conclusion that it at 75 degree Southern latitude. In $R/2$ model this corresponds to 60 degrees Southern latitude and ordinary glaciation proceeding from South Pole is a natural explanation and ordinary glaciation would be in question in both cases.

7. There is evidence for the continental ice cover does not fit with Snowball Earth predicts that there should be no continental ice-cover. The reason is that freezing of the ocean means that there is no evaporation from oceans and no water circulation so that ice-cover cannot develop on continents. There is considerable evidence that continents were covered by thick ice [F29]. This suggests ordinary glaciations possible in $R/2$ model.

8.5 TGD Point Of View About Pre-Cambrian Period

What is new in TGD based view about pre-Cambrian period is basically due to the $R/2$ hypothesis.

8.5.1 TGD view about evolution of continents

The hypothesis about the existence of the super-continent Pangea [F23] was inspired by the work of Wegener [F2]. The hypothesis about the existence of former super-continents were forced by the correlations with fossil records suggesting connected continent. This is not necessary if the gigantic ocean was absent during $R/2$ era. The continent Rodinia [F28] could look much like the Rodinia of standard geology except that they formed single connected region with radius $R/2$.

1. It is possible that there was only single super-continent with widening inland seas all the time until 250 billion Myr. The first option is R increased slowly and that inland lake formed. Rifts could have got wider gradually during this era. If there were land bridges between the continents there would be no need for postulating the cyclic re-formation of super-continent.

2. One can pose many questions about the character of the expansion.

   (a) What was the duration of the expansion? Could the expansion have occurred in the time period 750-100 Myr (100 Myr corresponds to the age of dinosaurs with large body size made possible by the reduced gravitation and oxygenation of the atmosphere)? Duration would have been about 650 Myr in this case. Or did it began already at the beginning of Neoproterozoic period [F18] when super-continent Rodinia began to break up? In this case the duration would be about 1 Myr. The estimate based on the quantum model of gravitational radiation predicts that the transition lasted for about 1.1 Gy so that the latter option would be more plausible in this framework.

   (b) Did the expansion accelerate as does also cosmic expansion in TGD based universal model for the expansion periods containing only the duration of the expansion period as a parameter [K24] and applying in alls scales? It seems that accelerated expansion is the only sensible option since around 540 Myr the size of Earth should have been rather near to $R/2$ (perhaps so even at the period of Pangea around 250 My) unless one assumes that super-continent re-formed again.

3. One can also consider the possibility that the continents indeed broke up and reformed again during Cambrian era. One should however have a good physical reason for why this happened. Something must have connected the pieces together and created correlations. Gravitational magnetic flux tubes and phase transitions increasing and reducing Planck constant? Or could it be that the bridges connecting the continents acted like strings inducing oscillation of the distance between continents so that Pangea was surrounded by a large ocean?

4. The formation of the rift [F27] feeding magma from core to the surface would be due to the expansion leading to the formation of fractures. The induced local elevations would be like mountains. As in zipper-rift model ice could have covered these plateaus because the temperature was lower. This is not however essential for TGD based model of glaciations.

5. TGD based variant of Expanding Earth allows subduction but its role could have been small before the Pangeia period if the expansion was accelerating and led only to a relatively small increase of the radius before the Mesozoic period [F16] and continued with an accelerating rate during Mesozoic from 250 Myr to 65 Myr. It is interesting that Mesozoic period begins with the most intensive known extinction of history- so called Permian-Triassic extinction event [I4] - known as Great Dying. About 95 of marine species and 70 percent of terrestrial species became extinct. Maybe genetically determined bio-rhythms could not follow the rapidly changing circadian rhythm. Another explanation for the extinction is the warming of the climate. For this there is indeed support: there is evidence that Antarctica was climate refuge during the extinction [I8]. Perhaps both factors were involved and were not independent of each other since rapid expansion might have generated massive methane leakages from underground seas and lakes.

8.5.2 TGD based view about evolution of oceans

Continents would have covered most of the area during $R/2$ era and the covered fraction was slightly smaller than 1/4 of the recent area of Earth. This depends on the area taken by inland seas and polar caps. Nowadays the area covered by continents and inland seas is about 31 per cent so that continental area has increased and would be due to the expansion in vertical direction and deepening of the oceans. The area covered by oceans has increased from a small value to about 70 per cent. Only a small fraction of ocean floor would be subduced in Expanding Earth model. The Proto-Atlantic would have been only a small inland sea. Panthalassic Ocean was inland sea, which expanded to Pacific Ocean during expansion. Pacific Ocean could contain data about ancient ice ages if it was frozen. It however seems that data are consistent with the absence of global glaciation.

8.5.3 Model for glaciations

In TGD framework single super continent covering most of Earth becomes the counterpart of Rodinia [F28]. The hypothetical oceans are replaced with inland seas and polar caps. The super-continent covering most of Earth absorbs less solar heat than tropical oceans so that glaciations become more probable. Snowball Earth is replaced with a series of ordinary glaciations proceeding from poles since the places at Equator were near North Pole. There is no need for the glaciations to progress to the equator. The rifting for the counterpart of Rodinia is consistent with the formation of fractures due to the expansion of Earth. The reduction of gravitational binding energy due to the increase of the radius requires feed of energy and this could be one reason for the cooling and initiation of the glaciation.

There are several questions which must be answered if one wants to gain a more detailed understanding.

1. How does $R/2$ model modify the view about glaciations? Very probably there was a frozen polar cap. Snowball Earth could be replaced with ordinary glaciations proceeding from North and South Pole.

2. How does the predicted 3+3 hour diurnal cycle modify the ordinary picture? Certainly 3-hour day reduces the amplitude of the diurnal temperature variations. Could this period have left genetic traces to the mono-cellulars, say biological clocks with this period?

3. How does the predicted four times stronger surface gravity affect the glaciation process? Could strong gravity leave detectable signatures such as anomalously strong effects on the shape of surface of Earth or deeper signatures about the motion of ice.

There are also questions related to the energetics of the expansion.

1. The expansion required energy and could have induce glaciations in this manner. Energy conservation would hold for the total mechanical and gravitational energy of Earth given by

$$E = \frac{L^2}{2I} - k\frac{GM^2}{R} < 0 \ . \tag{8.1}$$

Here L is the conserved angular momentum of order $L \simeq I\omega$ and ω increases from $1/4\omega_{now}$ to ω_{now} during the expansion. The moment of inertia I is of order of magnitude $I \sim MR^2$ and k is a numerical constant not too far from unity. The kinetic energy is actually negligible as compared to the gravitational potential energy. The reduction of the gravitational binding energy requires a compensating energy, which could come both from Earth interior or from the Earth's surface. Both effects would induce a cooling possibly inducing glaciations.

2. One expects that in the initial stages of the expansion there was just an expansion. This meant stretching requiring also energy. The formation of rifts leading to the formation of oceans as magma flowed out would have started already in the beginning of Proterozoic period. Eventually fractures were formed and in TGD framework one might expect that the distribution of fractures could have been fractal. A considerable fraction of fractures was probably volcanoes so that CO_2 begun to leak to the atmosphere and local "oasis" were formed. Also hot springs liberating heat energy from Earth crust could have been formed as in Island. The pockets inside Earth increased in size and were filled with water. Life started to escaped to the walls of the fractures and to the water pockets. Also the recent oceans can be seen as widened cracks which transformed to the expanding sea floors whereas continents did not expand. As the continental crust ceased to expand no heat was needed for the expansion and this together with increased CO_2 content of atmosphere would explain why there was no further glaciations and heating of the Earth. At this period the flow of the magma from Earth core provided the energy needed to compensate the reduction of gravitational energy.

3. It must be emphasized that TGD variant of Expanding Earth theory is not in conflict with tectonic plate theory. It explains the formation of tectonic plates and the formation of magma flow from rifts giving also rise to subduction and is therefore a natural extension of the tectonic plate theory to times before the expansion ceased.

8.5.4 Estimate for the duration of the transition changing gravitational Planck constant

The reader without background in quantum physics and TGD can skip this section developing an estimate for the duration of the transition changing Planck constant and inducing the scaling of the radius of Earth by a factor two. The estimate is about 1.1 Gy. It must be emphasized that the estimate is not first principle calculation and relies strongly on quantum classical correspondence.

The duration of the quantum transition inducing the expansion of the gravitational space-time sheet of Earth and thus of Earth itself by a factor two can be estimated by using the same general formula as used to estimate the power of gravitational radiation emitted in a transition in which gravitational Planck constant assignable to star-planet system is reduced [K21].

1. The value of gravitational Planck constant characterizing the gravitational field body of Earth is GM^2/v_0, where the velocity parameter $v_0 < 1$ ($c = 1$) is expected to be larger than $v_0 \simeq 2^{-11}$ characterizing Sun-Earth system.

2. Assuming a constant mass density for Earth the gravitational potential energy of Earth is given by

$$V = \frac{M}{2}\omega^2 r^2 \ , \ \omega = \sqrt{\frac{6GM}{R^3}} \ . \tag{8.2}$$

As far as radial oscillations are considered, the system is mathematically equivalent with a harmonic oscillator with mass M. The energies for the radial oscillations are quantized as $E = (n + 1/2)\hbar_{gr}\omega$.

3. The radii of Bohr quantized orbits for the harmonic oscillator scale like $\sqrt{\hbar}$ so that $\hbar \rightarrow 4\hbar$ is needed to obtain $R \rightarrow 2R$ rather than $\hbar \rightarrow 2\hbar$ as the naïve Compton length argument would suggest. This requires the scaling $v_0 \rightarrow v_0/4$. The change of the ground state energy in this quantum transition is

$$\begin{aligned} \Delta E &= \frac{1}{2}(\hbar_{gr,f}\omega_f - \hbar_{gr,i}\omega_i) \ , \\ \hbar_{gr,f} &= 4\hbar_{gr,i} = \frac{4GMm}{v_{0,i}} \ , \\ \omega_i &= 2^{3/2}\omega_f = 2^{3/2}\sqrt{\frac{6GM}{R_f^3}} \ . \end{aligned} \tag{8.3}$$

$R_f = R$ denotes the recent radius of Earth.

4. From the estimate for the power of gravitational radiation in similar transition the estimate for the duration τ of the quantum transition is

$$\begin{aligned} \tau &= a(v_{0,i}v_{0f})^{-k/2} \times \frac{(\hbar_{gr,i} + \hbar_{gr,f})}{2\Delta_E} \ , \\ &= a2^{-k}v_{0f}^{-k} \times \frac{1+r}{r\omega_f - \omega_i} \ , \ r = \frac{\hbar_f}{\hbar_i} = 4 \ . \end{aligned} \tag{8.4}$$

The average of Planck constants associated with the initial and final states and geometric mean of the parameters v_{0i} and v_{0f} is dictated by time reversal invariance. The exponent k is chosen to be same as that obtained for from the condition that the ratio of the power to the classical radiation power emitted in the transition between planetary Bohr orbits does not depend on v_0 (quantum classical correspondence). This gives $k = 5$. The condition that the power of gravitational radiation from Hulse-Taylor binary is same as the power predicted by the classical formula (quantum classical correspondence) gives $a = .75$.

5. The explicit expression for τ reads as

$$\begin{aligned} \tau &= K \times a v_{0,f}^{-5} \times (\frac{R}{2GM})^{1/2} \times \frac{R}{c} \ , \\ K &= \frac{5 \times 2^{-7} \times (2 + 2^{1/2})}{3^{1/2}} \ . \end{aligned} \tag{8.5}$$

6. The basic data are $M_{Sun} = 332900M$ (mass of Sun using Earth's mass as unit) and the mnemonic $r_{S,Sun} = 2GM_{Sun} = 2.95 \times 10^3$ m: together with $R = 6371 \times 10^3$ m these data allow a convenient estimation of $R/2GM$. For $k = 10$ and $a = .75$ this gives $\tau = 1.17$ Gyr. This is twice the estimate obtained by requiring that the transition begins at about 750 Myr (the beginning of Sturtian glaciation) and ends around 100 My (the age of gigantic animals whose evolution would be favored by the reduction of surface gravity). The estimate would suggest that the quantum transition began already around 1.1 Gyr, which in the accuracy used corresponds to the beginning of Neoproterozoic at 1 Gyr [F18]. The breaking of super-continent Rodinia indeed began already at this time.

7. Note that the value of v_{0f} for the gravitational field body of Earth as it is now would be $v_{0f} = 2^{-10}$ to be compared with $v_0 \simeq 2^{-11}$ for Sun-Earth gravitational field body.

8.5.5 Snowball Earth from TGD point of view

In TGD framework the main justification for Snowball Earth disappears since the samples believed to be from Equator would be from North pole and glaciation could be initiated from pole caps. Consider next in more detail the evidence for Snowball Earth from TGD point of view.

1. Low latitude glacial deposits, glacial sediments at tropical latitudes, tropical tillites, etc. providing support for snowball Earth [F29] would be near North pole of at Northern latitudes. Ordinary glaciations proceeding from poles would explain the findings [F10]. If total glaciations were present, a rough scaling suggests that the evidence from them should be found from southern latitudes around 45 degrees in the standard model framework.

   The testable prediction is that the evidence for glaciations in ice-ball Earth framework should be found only below Equator and near South Pole. This finding would be of course extremely weird and would strongly favor $R/2$ option. Interestingly, in Southern Brasil all indicators for glaciations are absent (see [F44] and references therein). This region belonged to Godwana continent and there is evidence that its location was at middle latitudes at Southern Hemisphere.

2. Banded iron formations [F29] are regarded as evidence for Snowball Earth and occur at tropical levels (near North Pole in $R/2$ model). Iron dissolved in anoxic ocean would have become in a contact with photosynthetically produced oxygen and implied the formation of iron-oxide. The iron formation would have been produced at the tipping points of anoxic and oxygenated ocean. One can consider also an explanation in terms of deep inland seas, which become stagnant and anoxic near the sea floor.

   In TGD framework sea floor near North Pole could contain banded iron formations. This would explain also why the banded iron formations are rather rare. The oxygen could have come also from underground after the formation of cracks and led to the oxygenation of inland seas from bottom. The assumption that oxygenation took place already during the first glaciation, could explain why banded iron formations are absent during the second glaciation.

3. Calcium carbonate deposits [F29] have ^{13}C signature (per cent for the depletion of ^{13} isotope and large for organic material) is consistent with that for mantle meaning abiotic origin. The explanation of Calcium carbonate deposits in TGD framework could be the same as in Snowball Earth model. Atmospheric CO_2 could come from the volcanoes and react with the silicates during the ice-free periods to form calcium carbonate which then formed the deposits. CO_2 could have also biological origin and come from the underground life at the walls of the expanding fractures/volcanoes or in underground seas or lakes. In this case also methane is expected. This option would predict ^{13}C signature characteristic for organic matter. Also this kind of signatures have been observed and support ordinary glaciations. Also rapid fluctuations of the signature from positive to negative take place and might have signatures of temporary melting induced organic contribution to the calcium carbonate.

4. Iridium anomaly [F29] is located at the base of Calcium Carbonate deposits. In Snowball Earth model Iridium deposits derive from the Iridium of cosmic rays arriving at the frozen ice surface. As the ice melts, Iridium deposits are formed. In $R/2$ model the condensation of Iridium would proceed through the same mechanism. The possible problem is whether the time is long enough for the development of noticeable deposits. Near poles (Equator and South pole in standard model) this could be the case.

8.6 Paleo-Magnetic Data And Expanding Earth Model

Paleomagnetic data from pre-Cambrian period might allow to test $R/2$ hypothesis. This data could in principle help to trace out the time development $R(t)$ from $R/2$ to R if the non-dipole contribution to magnetic field depends on $R(t)$.

8.6.1 About paleo-magnetism

Paleomagnetism [F22] provides quantitative methods to determine the latitude at which the sample of sedimentary rock was originally. Magnetic longitude cannot be determined because of rotational symmetry so that other information sources must be used. There are several methods allowing to deduce the direction and also the magnitude of the local magnetic field and from this the position of the sample during the time the sample was formed.

1. Below the Curie point thermal remanent magnetization is preserved in basalts of the ocean crust and not affected by the later magnetic fields unless they are too strong. This allows to deduced detail maps from continental drifting and polar wander maps after 250 Myr (Pangea period). During pre-Cambrian period the ocean floors of hypothetical oceans would have disappeared by subduction. In $R/2$ model there are no oceans: only inland seas.

2. In the second process magnetic grains in sediments may align with the magnetic field during or soon after deposition; this is known as detrital remnant magnetization (DRM). If the magnetization is acquired as the grains are deposited, the result is a depositional detrital remnant magnetization (dDRM); if it is acquired soon after deposition, it is a post-depositional detrital remnant magnetization (pDRM).

3. In the third process magnetic grains may be deposited from a circulating solution, or be formed during chemical reactions, and may record the direction of the magnetic field at the time of mineral formation. The field is said to be recorded by chemical remnant magnetization (CRM). The mineral recording the field commonly is hematite, another iron oxide. Red-beds, clastic sedimentary rocks (such as sandstones) that are red primarily because of hematite formation during or after sedimentary diagenesis, may have useful CRM signatures, and magnetostratigraphy [F15] can be based on such signatures. Snowball model predicts that nothing came to the bottoms of big oceans! How can we know that they existed at all!

During pre-Cambrian era the application of paleomagnetic methods [F22] is much more difficult.

1. Reliable paleomagnetic data range up to 250 My, the period of Pangaea, and magnetization direction serves as a reliable information carrier allowing detailed polar wander maps. During pre-Cambrian era one cannot use polar wander maps and the polarity of the magnetic field is unknown. Therefore theoretical assumptions are needed including hypothetical super-continents, hypothetical oceans, and continental drift and plate tectonics. All this is on shaky grounds since no direct information about super-continents and ancient oceans exists. $R/2$ model suggests that continental drift and plate tectonics have not been significant factors before the expansion period when only inland seas and polar ice caps were present. Measurements have been however carried out about magnetization for pre-Cambrian sediments at continents recently and gives information about the strength of the magnetic field [F14]: the overall magnitude of the magnetic field is same as nowadays.

2. At Precambrian period the orientation of iron rich materials can serve as a record. The original records can be destroyed by various mechanisms (diagenesis). Also the orientations of the sediments can change in geological time scales.

3. Tens of thousands of reversals of the magnetic polarity [F6] have occurred during Earth's history. There have been long periods of stability and periods with a high frequency of reversals. The average duration of glaciation is around one Myr. The determination of the polarity of B possible by using samples from different points.

4. Mountain building orogeny [F21] releases hot water as a byproduct. This water can circulate in rocks thousands of kilometers and can reset the magnetic signature. The formation of fractures during the expansion of Earth could have released hot water having the same effect.

8.6.2 Could paleomagnetic data kill or prove $R/2$ model?

The first question is how one might kill $R/2$ model using data from pre-Cambrian era. Paleomagnetic data could do the job.

1. Remanent magnetization is proportional to the value of magnetic field causing it in weak magnetic fields. Therefore the magnetization in principle gives information about the magnetic fields that prevailed in early times.

2. Suppose that the currents generating the magnetic field can be idealized to conserved surface currents K around cylindrical surfaces of radius r and height h scaled down to to $r/2$ and $h/2$ and that the value of K is not affected in the process. With this assumptions the magnetic moment behaves $\mu \sim Ir^2h \rightarrow \mu/8$. A continuous current vortices with $j = k/\rho$, which is ir-rotational outside the symmetry axis, produce a similar result if the radius of the vortices scales as $r \rightarrow r/2$. Since dipole magnetic field scales as $1/r^3$ and is scaled up by a factor 8 in $R \rightarrow R/2$, the scalings compensate and the dipole magnetic fields at surface do not allow to distinguish between the two options. Non-dipole contributions might allow to make the distinction.

3. The group led by Lauri J. Pesonen in Helsinki University [F14] has studied paleomagnetic fields at pre-Cambrian era. The summary of results is a curve at the home page of the group and shows that the scale of the magnetic during pre-Cambrian era is same as nowadays. On the other hand, the recent thesis by Johanna Salminen- one of the group members- reports abnormally high values of magnetization in Pre-Cambrian intrusions and impact structures in both Fennoscandia and South Africa [F40]. No explanation for these values has been found but it is probably not the large value of primary magnetization.

Another manner to do test the $R/2$ model is by comparing the signs of the magnetizations at magnetic equator and poles. They should be of opposite sign for dipole field. The polarity of magnetic field varies and there are no pre-Cambrian polar wander maps. One can deduce from the condition $B_r/rB_\theta = 2cot(\theta)$ holding true for dipole field the azimutal distance $\Delta\theta$ along the direction of the measured magnetic field to the pole along geodesic circle in the direction of the tangential component of B. One cannot however tell the sign of $\Delta\theta$, in other words whether a given pre-Cambrian sample belongs to Norther or Southern magnetic hemisphere. There are however statistical methods allowing to estimate the actual pole position using samples from several positions (for an excellent summary see [F40]).

For instance, if the magnetic field is in North-South direction during Rodinian period [F28], standard model would predict that the sign at the Equator is opposite to that at South Pole. In $R/2$ model the sample would be actually near North Pole and polarizations would have same sign. The sign of magnetization at apparent southern latitude around 45 degrees would have been opposite to that at South pole which is in conflict with dipole field character. Maybe the global study of magnetization directions when magnetic field was approximately in North-South direction could allow to find which option is correct. Also the dependence of the strength of the magnetic field as function of θ could reveal whether $R/2$ model works or not. The testing requires precise dating and position determination of the samples and a detailed model for the TGD counterpart of Rodinia and its construction requires a specialist.

If the expansion continued after 250 Myr with an accelerating rate and Earth radius was still considerably below its recent value, the comparison of pole wandering charts deduced from ocean floor paleomagnetic data at faraway locations might allow to show that the hypothesis about dipole field is not globally consistent for R option. Even information about the time evolution of the radius could be deduced from the requirement of global consistency.

8.7 Did Life Go Underground During Pre-Cambrian Glaciations?

The basic idea of Expanding Earth model is that the life developed in underground seas and emerged to the surface of Earth in Cambrian explosion. The series of pre-Cambrian glaciations explains why the life escaped underground and how the underground seas were formed.

1. If one believes that the reduction of gravitational binding energy was responsible the cooling, then the expansion of Earth could have begun at the same time as Sturtian glaciation [F3] . On the other hand, the TGD estimate for the duration of the expansion period giving 1.1 Gyr, suggests that the breakup of the Rodinia, which began in the beginning of Proterozoic period corresponds to the beginning of the expansion. The simplest assumption is that the radius of R at the beginning of Cambrian period was not yet much larger than $R/2$ and continued to increase during Cambrian period and ended up around 100 My, when dinosaurs and other big animals had emerged (possibly as a response to the reduction of gravity). This means that there were land bridges connecting the separate continents.

2. One must explain the scarcity of fossils during pre-Cambrian era. If the more primitive life forms at the surface of Earth did not have hard cells and left no fossils one can understand the absence of highly evolved fossils before Cambrian explosion [I1]. If life-forms emerged cracks and underground seas there would be no fossils at the surface of Earth. In the case of volcanoes dead organisms would have ended to gone to the bottom of the water containing volcano and burned away.

3. The expansion had formed the underground pockets and fractures made possible for the water to flow from the surface to the pockets. Life would have evolved in fractures and pockets. The first multicellular fossils appeared during Ediacaran period (segmented worms, fronds, disks, or immobile bags) [F4] and have little resemblance to recent life forms and their relationship with Cambrian life forms is also unclear. Ediacaran life forms could have migrated from the fractures and Cambrian fossils from from the underground seas and lakes. The highly evolved life-forms in Cambrian explosion could have emerged from underground seas through fractures.

One can make also questions about the underground life.

1. The obvious question concerns the sources of metabolic energy in underground seas. In absence of solar radiation photosynthesis was not possible plants were absent. The lowest levels in the metabolic hierarchy would have received their metabolic energy from the thermal or chemical energy of Earth crust or from volcanoes. The basic distinction between plants and animals might be that the primitive forms of plants developed at the surface of Earth and those of animals in underground seas.

2. At first it seems strange that the Cambrian life-forms had eyes although there was no solar radiation in the underground seas. This is actually not a problem. These life-forms had excellent reasons for possessing eyes and in absence of sun-light the life forms had to invent lamp. Indeed, many life forms in deep sea and sea trenches produce their own light [I3]. It would be interesting to try to identify from Cambrian fossils the body parts which could have served as the light source.

8.8 Great Unconformity As A New Piece Of Support For Expanding Earth Model

I hope that this chapter demonstrates convincingly that single hypothesis - a sudden phase transition increasing the radius of Earth by a factor 2 natural in the many-sheeted space-time of TGD - explains Cambrian explosion in biology (a sudden emergence of huge number of life forms after very slow Precambrian evolution), and also provides a model for Precambrian evolution of continents, climate and life.

Already Darwin realized that the absence of fossils from Precambrian era (see `http://tinyurl.com/65zeh5`) is a deep problem for his theory and assumed that this is an artefact due to the incomplete fossil record. Fossils of Precambrian origin have been indeed found after Darwin's time but they are simple and very rare, and the conclusion is that Cambrian explosion (see `http://tinyurl.com/3flhcw`) [I1] meaning a huge diversification was real. Two mysteries therefore remain. Why the development of life was so slow during Precambrian era? Why the diversification was so incredibly fast during Cambrian explosion? Various explanations have been proposed. Did the oxygen content of the atmosphere reach a critical value and lead to the diversification? Or did predation pose the evolutionary pressure making the pace of evolution dramatically faster?

In New Scientist (see `http://tinyurl.com/nenk8nq`) [F39] geologists Robert Gaines and Shanan Peters describe a geological finding perhaps related to the Cambrian Explosion: the mysterious "Great Unconformity" (see `http://tinyurl.com/bqm9ndz`) [F9], which is a juxtaposition of two different types of rock of very different geological ages along a prominent surface of erosion. This surface represents a very long span of "missing" time. More than 1 billion years of geological record is missing in many places! From the figure (see `http://tinyurl.com/y8tnbneb`) of the Wikipedia article [F9] about Great Unconformity visible in Grand Canyon the thickness of the missing layer can be estimated to be about 12.6 km. Somehow before the Cambrian the uppermost rocks of the continents were stripped away exposing the underlying crystalline basement rocks. The cause of this gap remains a complete mystery so that we have three mysteries! Plus the mysteries related to the evolution of climate (problems of Snowball Earth model).

The authors suggest that the formation of Great Unconformity relates to the Cambrian explosion. Large scale erosion and chemical weathering of the exposed crystalline rock caused mineralization of the sea water. The hypothesis is that this led to bio-mineralization: animal groups possessing mineral skeletons - such as silica shells and calcium carbonate shells - emerged. This hypothesis looks rather plausible but does not solve the three great mysteries.

The authors indeed leave open the question about the origin of Great Unconformity and of Cambrian explosion. The TGD based explanation of Cambrian explosion comes from the model realizing the old idea about Expanding Earth in terms of TGD inspired new physics. Already Wegener observed that continents can be fit together nicely and this led to the recent view about plate tectonics. Wegener's model however fits only "half" of the continent boundaries together. One could however do much better: the observation is that the continents would fit nicely to cover the entire surface of Earth if the radius of Earth were 1/2 of its recent value! Expanding Earth model postulates that the radius of Earth grows slowly. Geologists have not taken Expanding Earth model seriously: one good reason is that there is no physics allowing it.

As has been found, TGD predicts a candidate for the needed new physics.

1. At given sheet of the many-sheeted space-time cosmic expansion is predicted to take place as sudden phase transitions in which the size of some space-time sheet suddenly increases. By p-adic length scale hypothesis the preferred scaling factors are powers of 2 and the most favored scaling factor is just two. The proposal is that during the Precambrian era life resided in underground seas being thus shielded from meteor bombardment and cosmic rays. This explains the scarcity of the fossil records and the simplicity of the fossils found. The sudden phase transition was a very violent process increasing the area of the Earth's surface by a factor of 4. The area of continents is 29.1 per cent from the recent area of the Earth's surface - not too far from the naïvely predicted fraction 1/4.

2. It is easy to imagine that the uppermost rocks of the continent covering the entire Earth were stripped away and correspond nowadays to 100 km thick continental tectonic plates consisting of mainly silicon and aluminium). This expansion created split first the topmost layer as continental plates and regions between them giving rise to oceans. The magma which was uncovered by the process cooled down and solidified and the continued expansion gave rise to ocean plates with different composition (mainly silicon and magnesium).

3. The expansion phase corresponds to criticality so that fractality of the expansion is expected. At least for continental plates this process could have been fractal occurring in various length scales characterizing the thickness and the area of the sub-plates generated in the process. p-Adic length scale hypothesis suggests that the scales involved should appear as powers of $\sqrt{2}$ or 2. Generation of Great Unconformity as a process in which the underlying crystalline basement rocks were uncovered could correspond to a splitting of a layer of the continental plates to pieces. The length scale characterizing the thickness is 12.6 km from the above estimate and with 1 per cent accuracy by a factor 1/8 shorter than 100 km length scale for tectonic plates. This conforms with p-adic fractality. If the process of expansion involved a cascade of scalings by factor 2, one can wonder whether it proceeded from long to short length scales or vice versa. In other words: did continental and oceanic tectonic plates form first and after than the smaller structures such as the Great Unconformity or vice versa?

4. Note that the Compton scale $L_e(237)$ corresponding $p \simeq 2^{237}$ is 88 km - ten per cent smaller

than 100 km. Maybe thermal expansion could account the discrepancy if the original thickness was $L(237)$. Second interpretation could be that besides electron Compton scale $L_e(239)$ the p-adic scale $L(239) = L_e(239)/\sqrt{5} \simeq 78.7$ km matters. The importance of $L(k)$ does not implicate that of scaled up electron, and the following argument suggests that it is p-adic length scale rather than corresponding electron Compton scale that matters now. Remarkably, also M_{241} is Gaussian Mersenne and corresponding electronic Compton scale is $L_e(241) = 154.7$ km.

Note that 88 km is rather precisely the thickness of the atmosphere above which there is ionosphere (see `http://tinyurl.com/lqr85j`) [F11]. The thickness of Kennelly–Heaviside layer (see `http://tinyurl.com/25ur2tl`) [F12] inside which radio waves used in terrestrial radio communications propagate, has thickness about 150 km which roughly corresponds to $L(239)$. Note that Continental litosphere (see `http://tinyurl.com/d96kw`) [F26] has typical thickness of 200 km ($L(239)$) whereas oceanic litosphere is 100 km thick ($L(237)$). This fits at least qualitatively with the proposed formation mechanism of continental tectonic plates.

There is a nice fractal analogy with cell membrane and connection with Gaussian Mersennes (see `http://tinyurl.com/pptxe9c`) [?] expected to be of special importance in TGD Universe. The scales $L(239)$ and $L(241)$ would be in the same relation as the thickness $L_e(149)$ of the lipid layer of cell membrane to the cell membrane thickness $L_e(151)$ characterized by Gaussian Mersenne $M_{151,G}$. The two kinds of tectonic plates (continental and oceanic) would be analogous to the lipid layers of cell membrane.

5. The rapid expansion process could have also brought in daylight the underground seas and the highly developed life in them so that Cambrian diversification would have been only apparent. Skeptic can of course ask whether it is necessary to assume that life resided in underground seas during Precambrian era. Could just the violent geological process be enough to induce extremely fast diversification? This might of course be true.

6. There is one further argument in favor of the Expanding Earth model. The fact that the solar constant was during proto Earth period (see `http://tinyurl.com/pc83uvt`) [F33] only 73 per cent from its recent value, is a problem for the models of the very early evolution of life. If the radius of Earth was 1/2 of its recent value the duration of day and night was from conservation of angular momentum only 1/4: th of the recent value and thus 3 hours. This could have made the environment much more favorable for the evolution of life even at the surface of the Earth since the range for the temperature variation would have been much narrower.

8.9 Where Did The Oceans Come From?

TGD based vision about life has been developing rapidly thanks to the realization that hierarchy of Planck constants and dark matter could relate directly to criticality: consider only long range correlations, phase separation, and classical non-determinism near critical point as common aspects [K15]. The article "Half of the Earth's water formed before the sun was born" (`http://news.sciencemag.org/earth/2014/09/half-earths-water-formed-sun-was-born`) describes research results proving additional support for the TGD inspired idea about the occurrence of prebiotic evolution in underground water reservoirs shielded from meteorites and cosmic rays. The idea relies on TGD inspired variant of Expanding Earth hypothesis [K21, K6].

1. Article represents first a standard argument in favor of late formation of oceans. The collisions by astreroids and meteorites could have evaporated the water or blown off it in to space. Hence surface water at Earth should have emerged much later. Note that one can replace "water" with "life" in the argument.

2. The researchers end up to propose that the water emerged already before Sun, and also oceans did so rather early. Carbonaceous chondrites (`http://tinyurl.com/75fh74p`), which formed at the same time as Sun and well before the planets, could have served as a source of water. These meteorites were formed very early, already earlier than Sun. Their composition resembles that of bulk solar system composition. By studying basaltic meteorites from

asteroid Vesta, which is known to be formed in the same region as Earth, the reaseracher found that they contain same hydrogen isotopic composition as carbonaeous chondrites.

This motivates the proposal that chondrites contained the water. A further proposal is that the water reservoirs formed at the surface of Earth as it formed. Here I beg to disagree: the objection represented in the beginning is difficult to circumvent!

The article stimulates several interestig questions in TGD based conceptual framework.

1. Why not to assume formation of underground water reservoir? Here meteorites and UV radiation did not form a problem. And there is indeed recent evidence for the previous existence of large underground reservoirs (`http://tinyurl.com/k2d2ttj`). The formation process for Earth could have naturally led to the evaporation of of chondrite water from the interior of Earth and its transfer nearer to surface and getting caught inside reservoirs.

   Also prebiotic life could have evolved in the underground water reservoirs and already in chondrites (DNA, RNA, aminoacids, tRNA represented as dark proton sequences at flux tubes) and transformed to the life as we know. Mother Gaia's womb was nice place: no meteorite bombardment, no cosmic rays, and metabolic energy provided by Mother Gaia as dark photons. Cambrian explosion as Earth's radius increased by a factor of two was the birthday of the life as we identify it, the (child) water burst to the surface and seas were formed and life began to evolve at the surface of Earth.

   Recall that in TGD continous cosmological expansion at level of space-time sheets is at quantum level replaced with a sequence of phase transitions increasing $h_{eff} = n \times h$ and/or p-adic length scale of the space-time sheet - by p-adic length scale hypothesis most naturally by a factor of two. This kind of transition explains why the continents of Earth fit nicely together to cover entire Earth if the radius is half of its recent value, the emergence of gigantic life forms, etc... [K6].

2. The basic objection relates to the basic mechanisms of metabolism. What replaced plants receiving metabolic energy from solar light as source of metabolic energy? What replaced Sun? Did the dark photon radiation generated by Earth - or maybe also Sun - and penetrating ordinary matter as dark radiation, replace sun light? Any critical system could generate this radiation and it should not be difficult to identify this kind of system: the boundary between core and mantle is the most obvious candidate for a critical system as also for a rapid self-organization process). I proposed for more than decade ago this option half-jokingly as metabolic sources of IT (intraterrestrial) life as I called it.

3. Dark photon radiation would have had a universal energy spectrum - the spectrum of biophotons in visible and UV range. Part of it would have transformed to biophotons (`http://tinyurl.com/yb9hnmu7`) taking the role of solar radiation as a metabolic energy source. An interesting question is whether the life at the bottom of oceans could give some hints about the counterpart of photosynthesis based on bio-photons? The discovery that the metabolic reactions thought to require complex catalytic maschinery can take place in the environment simulating ocean bottom (`http://tinyurl.com/ydc8g7r4`) supports the idea about the evolution of life from prebiotic life forms in the womb of Mother Gaia. In TGD framework these prebiotic life forms could correspond to dark proton sequences (dark nuclei) at magnetic flux tubes associated with the negatively charged exclusion zones discovered by Pollack [I5] (`http://tinyurl.com/oyhstc2`).

9 Do Blackholes And Blackhole Evaporation Have TGD Counterparts?

The blackhole informationparadox (see `http://tinyurl.com/9a58c`) is often believed to have solution in terms of holography stating in the case of blackholes that blackhole horizon can serve as a holographic screen representing the information about the surrounding space as a hologram. The situation is however far from settled. The newest challenge is so called firewall paradox proposed by Polchinsky *et al* (see `http://tinyurl.com/oqfwf27`) [B6]. Lubos Motl has written several postings about firewall paradox and they inspired me to look the situation in TGD framework.

These paradoxes strengthen the overall impression that the blackhole physics indeed represent the limit at which GRT fails and the outcome is recycling of old arguments leading nowhere. Something very important is lacking. On the other hand, some authors like Susskind claim that the physics of this century more or less reduces to that for blackholes. I however see this endless tinkering with blackholes as a decline of physics. If super string had been a success as a physical theory, we would have got rid of blackholes.

If TGD is to replace GRT, it must also provide new insights to blackholes, blackhole evaporation, information paradox and firewall paradox. This inspired me to look for what blackholes and blackhole evaporation could mean in TGD framework and whether TGD can avoid the paradoxes. This kind of exercises allow also to sharpen the TGD based view about space-time and quantum and build connections to the mainstream views.

9.1 Background

9.1.1 Hawking radiation and information paradox

A theoretical argument supporting the existence of Hawking radiation (see `http://tinyurl.com/bohvd`) from blackhole was suggested by Hawking in 1974. Before this Bekenstein had proposed that blackhholes are characterized temperature and entropy. The implication is that blackholes radiate their mass gradually as thermal radiation. Since thermal radiation carries no information, this leads to black hole information paradox (see `http://tinyurl.com/9a58c`) if one assumes that the blackhole evolves unitarily.

Hawkings's original conclusion - which he later gave up - was that information is indeed lost. Susskind and t'Hooft proposed holographic principle stating that the information is actually contained in the radiation emitted from the blackhole. There are several approaches to the information paradox: information is destroyed, information gradually leaks out, information suddenly escapes in the final states of evaporation, or is stored in Planck sized remnant. Basic assumptions have been Equivalence Principle and unitary of the emission process of blackhole evolution. Penrose's disagreed about the necessity of assuming unitary evolution: state function reduction is non-unitary process and his proposal was that gravitation induces state function reductions.

9.1.2 Firewall paradox

The firewall paradox was introduced by Polchinski *et al* (see `http://tinyurl.com/oqfwf27`). One considers two observers: distant observer and observer falling in late stage blackhole. If one assumes both Equivalence principle in the sense that M^4 QFT applies in low curvature regions (therefore also somewhat below the horizon) and requires unitary of emission of Hawking radiation, one ends up with the prediction that falling observer must encounter a firewall at horizon (quite concretely destroying her) or there is new non-local long length scale dynamics involved. EP however predicts that no such firewall should be encountered since low curvature regions are in question and M^4 QFT should work. Therefore unitary and EP lead to conflicting predictions.

In the following Bob refers to distant observer and Alice is the observer jumping into blackhole. The core of the argument goes as follows.

1. Bob: Unitarity requires maximal entanglement BR, R early Hawking radiation. If one assumes that entanglement matrix is unitary or product of projection operator and unitary matrix then this is the case but I do not quite understand why this should be the case.

2. Alice: Horizon approximated by Rindler wedge (see `http://tinyurl.com/msr3p4`) [B4, B5, B3]. Minkowski vacuum superposition of state pairs at different sides of the Rindler wedge. Nearly maximal entanglement for Minkowski vacuum represented in terms of states associated with the right and left wedges is easy to understand. EP requires maximal entanglement BA, A inside blackhole. Therefore B is maximally entangled with both A and R. This is contradiction by the monogamy of maximal entanglement (more precisely with the subadditivity of entanglement entropy).

There has been an intense debate about the firewall paradox. For instance, Bouzzo has written two articles with different conclusions.

Bouzzo's first article has title "Observer complementary resolves firewall paradox" (see http://tinyurl.com/yc752cuj) [B9]. The argument goes as follows. By EP Alice falling in blackhole can approximate local physics in low curvature regions by the physics in empty Minkowski space: the region above and also somewhat below horizon is low curvature region. Blackhole looks like membrane for Bob. Alice observers no membrane. Therefore the descriptions of the two observers are inconsistent. Observer complementarity is claimed to save the situation. Observers are not able to communicate to each other their contradictory findings concerning the existence horizon, and therefore cannot discover the inconsistency. The measurements of Alice and Bob are analogous to measurement of non-commuting observables. These are to my opinion lawyer arguments. Laws of physics could be violated when no-one is seeing it!

Bouzzo's second article is titled Observer complementarity is not enough (see http://tinyurl.com/y97qz8jw) [B8]. The new argument developed by Bouzzo states that Alice can actually gather information about the existence of horizon and avoid falling into blackhole and therefore communicate the information to Bob so that paradox becomes observable.

To my opinion observer complementary and blackhole complementarity (see http://tinyurl.com/ybkrtsoc) suggested by Susskind [B10] and involves the assumption of stretched horizon with thickness of Planck length sound questionable hypothesis.

9.2 About Basic Assumptions About Blackhole Evaporation As Seen In TGD Context

1. For GRT blackholes the interior does not allow geodesic lines to escape to blackhole exterior: in other words the escape velocity is larger than light velocity. Also the roles of time coordinate and radial coordinate are exchanged.

   In TGD sub-manifold gravity leads the replacement of blackhole interior with an Euclidian region [L1] (see http://tinyurl.com/hzkldnb. Motivation for this comes from the study of small perturbations of the Reissner-Nordström metric transforming horizon to light-like 3-surfaces and making 4-metric degenerate at horizon so that Euclidian metric signature becomes natural in the interior. This leads to a new view about the microscopic origin of cosmological constant: there are actually many ways to interpret cosmological constant and the recent progress in the understanding of preferred extremals predicts Einstein's equations with cosmological constant which - like also Newton's constant- can in principle depend on extremal [K12], and perhaps be even replaced with several analogs of cosmological constant which are position dependent: it seems that this option is not promising.

   Horizon property is preserved since nothing can escape from Euclidian region to Minkowskian region. The reason is that in Euclidian region the square of four-velocity is negative and in Minkowskian region positive or zero unless a tachyon is in question. Note that the 4-metric becomes degenerate at horizon in time direction. Minkowskian QFT description inside TGD blackhole is definitely lost. As a matter of fact, it seems that any physical object by definition corresponds to a system with horizon in which the signature of the induced metric changes. One can also say that any physical object can appear as a line of generalized Feynman diagram understood as Euclidian space-time region whose M^4 projection can be arbitrarily large. Blackholes would be replaced with a much larger variety of objects with horizon to which an appropriate generalization of the ideas of blackhole physics might apply. This would represent TGD counterpart for AdS/CFT correspondence with AdS replaced with space-time surface and conformal field theory assigned with light like 3-surface and partonic 2-surface and tangent space data by strong form of holography.

2. The assumption about fixed space-time might be unacceptable in the case of blackhole even in the length scales of order Schwarzschild radius.

   In TGD framework the notion of many-sheeted space-time (see **Fig. ??** in the appendix of this book) leads to the hierarchy of effective Planck constants [L2]. This hierarchy suggests that black holes could be macroscopic quantum systems. In particular, the degrees of freedom associated with the "world of classical worlds" (WCW) could not be approximated as being frozen anymore so that QFT description would fail. Even outside the blackhole the presence of magnetic flux quanta suggested to mediate gravitational and also other interactions [K23] brings in new highly non-trivial essentially non-local degrees of freedom.

3. In GRT framework EP is assumed in the form that M^4 QFT describes physics locally in the low curvature regions, and applies also below horizon as long as curvature is not too large.

   In TGD framework this form of EP need not make sense in TGD, and certainly not so at the boundary of Minkowskian and Euclidian regions defining the TGD counterpart of blackhole horizon. EP as Einstein's equations makes sense in TGD although the equations do not follow from a variational principle but as a property of preferred extremals guaranteeing a generalization of 2-D conformal invariance to 4-D context. Gravitational constant and parameter Λ are predictions of classical theory rather than inputs.

4. Blackhole thermodynamics suggests that information about the state of matter collapsed into blackhole is lost. This leads to blackhole information paradox (see `http://tinyurl.com/9a58c`).

   The Unruh effect (see `http://tinyurl.com/28xm9o`) [B4, B5] (see `http://tinyurl.com/msr3p4`) suggests a possible solution to the problem.

   (a) Consider a system accelerated with constant acceleration a. A convenient coordinate system is $M^2 \times E^2$ such that acceleration in M^2. The coordinates for M^2 are 2-D variant of Robertson-Walker coordinates: $(t,x) = a(sinh(\eta), \pm cosh(\eta))$, where $\pm$ corresponds to the two disjoint components L and R of the set $t^2 - x^2 < 0$ of M^2. The orbit of the accelerated system correspond to the $a = constant$ hyperbola with a proportional to the inverse of acceleraton. At the limit of infinite acceleration one obtains orbit at the boundary of 2-D light-cone defining Rindler horizon (see `http://tinyurl.com/y7k4vvwq`) [B3].

   (b) For an accelerated observer it is natural to quantize field theory in the right wedge R and the vacuum of full M^4 QFT is sum over products of state in L and R. For large values of acceleration these states have nearly maximal entanglement. The tracing over L or R yields thermal density matrix with temperature equal to $a/2\pi$, a the acceleration.

   (c) The analogies with blackhole horizon are obvious, which leads to the idea that Hawking radiation is like Unruh radiation and Hawking temperature is analogous to Unruh temperature. The problem is that speaking about acceleration in Minkowski space in GRT, where geodesic motion corresponds to a vanishing acceleration, does not seem to make sense.

   TGD can be seen as sub-manifold gravity and this changes the situation. The geodesic lines at space-time surface are not geodesic lines of the embedding space, and therefore have non-vanishing trace of second fundamental form as curves of embedding space rather than space-time surface. The M^4 part of the second fundamental form defines acceleration. What is also intriguing that $M^4 = M^2 \times E^2$ decomposition appears in quantum TGD at fundamental level having both purely physical and number theoretical justification. Could this decomposition define also the analogs of Rindler wedges and Unruh decomposition? Could one see the TGD counterpart of Hawking gravitation as a "kinematic effect" very much analogous to Unruh radiation?

5. Blackhole time evolution is assumed to be unitary and Hawking evaporation is assumed to be a unitary process.

   In TGD M-matrix replaces S-matrix identifiable as a product of hermitian square root of density matrix and unitary universal S-matrix [K13]. M-matrices and thus hermitian square roots define an orthonormal basis. The original mathematically attractive idea that U-matrix reduces to a unitary U-matrix constructed from M-matrices by taking them as rows turned out to be wrong.

   The M-matrices associated with CDs obtained by a discrete scaling characterized by integer n from the minimal CD are naturally proportional to S^n, where S is the S-matrix associated with the minimal CD. This conforms with the idea about unitary time evolution as exponent of Hamiltonian discretized to integer power S^n of S.

U-matrix elements between M-matrices for various CDs are proportional to the inner products $Tr[S^{-n_1} \circ H^i H^j \circ S^{n_2} \lambda]$, where λ represents unitarily the discrete Lorentz boost relating the moduli of the active boundary of CD and H^i form an orthonormal basis of Hermitian square roots of density matrices. $\circ$ tells that S acts at the active boundary of CD only. I turns out possible to construct a general representation for the U-matrix reducing its construction to that of S-matrix.

Quantum dynamics can be seen as a sequence of quantum jumps to which one can assign state preparation, state function reduction and unitary process. At ensemble level (for sub-CDs of CD) one has dissipation and blackhole like system is like any other macroscopic quantum system. There is also hierarchy of space-time sheets and small space-time sheets defined dissipating ensembles. The entire system however behaves unitarily. In reality one must take also the interactions of blackhole with environment into account so that exact unitary holds only for this system.

In TGD based quantum theory state function reduction (describe in more detail in the chapter "About the Nature of time" (see `http://tinyurl.com/yblbzk6x`) [K1] is the basic element of quantum dynamics. One has sequences of unitary evolutions followed by state function reductions. TGD space-time is many-sheeted so that these evolutions appear in many scales characterized by the size scales of causal diamonds (CDs). In the scale of CD assignable to blackhole the time scale characterizing the unitary evolution at the space-time sheet of blackhole is certainly very long so that unitary at this space-time sheet should be a good approximation. For small sub-CDs situation changes and one can assign the ensembles formed by them growing entropy.

6. In quantum gravity Planck length scale is often assumed to be something fundamental. This could quite well be an illusion produced by dimensional analysis.

   In TGD framework CP_2 length scale which is of order 10^4 times Planck length scale defines the fundamental length scale with concrete geometric interpretation and Planck length scale emerge only as formal scale which need not have any geometrical correlate.

7. In TGD framework the replacement of fixed space-time with WCW spinor field defined as quantum superposition of space-times resolves the problems related to black holes according to general relativity and string theory. One can say that unique space-time "emerges" as a useful but fictitious notion analogous to electron's orbit in hydrogen atom.

9.3 Relating The Terminology Of Blackhole Evaporation To TGD Framework

It is useful to consider the terminology related to blackhole, black hole evaporation, and entanglement from TGD point of view.

9.3.1 Blackhole and observers

1. *Horizon*: the surface inside which the escape velocity for particles larger than c. Time coordinate and radial coordinate change their roles. For the embedding of Schwarzschild metric in $M^4 \times CP_2$ this happens quite concretely.

   In TGD interior of blackhole like state has Euclidian metric and the boundary between Minkowskian and Euclidian regions acts like a causal horizon.

2. *Stretched horizon*: Horizon replaced with a layer of thickness Planck length.

   This notion could has a counterpart in TGD although the scale in question is much larger than Planck length. Particles just outside the TGD horizon as wormhole contacts connected by magnetic flux tubes to the horizon which is very large wormhole contacts as far as M^4 projection is considered.

3. *Rindler wedges*: Blackhole horizon approximated as Rindler horizon in GRT. One approximates the situation using QFT in $M^4 = M^2 \times E^2$ where M^2 has hyperbolic coordinates motivated by the fact that the orbit of particle with constant acceleration is hyperbola. Minkowski vacuum in the accelerating system described by right Rindler wedge is seen as almost maximally entangled state in tensor product of the two sides of the wedge. In GRT framework this approximation is questionable since acceleration is questionable notion: it vanishes for geodesic lines.

   What about TGD?

   (a) In TGD framework blackhole horizon cannot be approximated as Rindler horizon since the interior of TGD blackhole is Euclidian. What is how intriguing that $M^2 \subset M^4$ inclusion appears in TGD framework in key role. Also Rindler wedge involves preferred M^2 determined by the direction of acceleration. The trace of the second fundamental form defines acceleration like variable for any sub-manifold and for 1-D curve in particular. Only the right Rinder wedge is realized as Minkowskian region at wormhole throats. Therefore it does not make sense to speak about Unruh effect and Hawking radiation at horizon since Minkowski vacuum is not a sensible approximation here.

   (b) Generalized form of holography however suggests that horizon is mathematically and physically equivalent with any parallel light-like 3-surfaces forming a slicing around the horizon. For them Rindler wedges make sense and one would obtain the analog of Hawking radiation as Unruh effect.

   (c) Rindler edges could be also interpreted as outside of the CD and the motion of particle in this region as motion in gravitational field created by matter outside CD. CD resembles blackhole at the level of embedding space. Outside has also interpretation in terms of interior of another CD.

9.3.2 Entanglement

There are some notions related to entanglement. Purifying entanglement for density matrix of system B means existence of a system R_B such that $R_B B$ is pure - in other worlds the density matrix of B is obtained by tracing over R_B.

Almost maximal entanglement means that the density matrix of second entangled system obtained by tracing is in near unit matrix. The monogamy of maximal entanglement states that a given system cannot have maximal entanglement with to disjoint systems is the core of the argument leading to the firewall paradox.

Alice is argued to see a mirror system inside horizon maximally entangled with Bob: $A \heartsuit B$ in the notation half-jokingly introduced by Lubos Motl Notl who seems maximal entanglement as love (personally I prefer see negentropic entanglement as correlate of love and various kinds of positive emotions such as experience of understanding).

9.3.3 Hawking radiation

Early radiation R and late radiation R' are assumed to combine to form a pure state RR', which is maximally entangled. If a unitary matrix multiplied by a projection operators to R and R' (P_1SP_2) defines the entanglement coefficients, maximal entanglement is obtained.

What could this correspond in TGD? Zero energy ontology (ZEO) implies that density matrix is replaced with M-matrix defining time-like entanglement coefficients. M-matrix as counterpart of S-matrix is not unitary. Unitary matrix U however exists and has M-matrices as its rows. Quantum evolution is a sequence of quantum jumps reducing to state function reductions at the upper and lower boundaries of CD. Unitary evolution relates to each other the two basis of zero energy associated with opposite boundaries. These differ in that positive/zero energy part of state is prepared whereas the second part of state is superposition of states with different particle numbers and with ill-defined single particle quantum numbers.

9.4 Could Blackhole Evaporation Have A TGD Counterpart?

Basically any burning process is analogous to blackhole evaporation in TGD framework since Euclidian region defines a space-time counterpart for a system in any length scale. Blackhole is different only because the gravitational field outside horizon is so strong that its stability with respect to small perturbations forced the generation of Euclidian region. This is enough to explain what we can observe about blackholes.

9.4.1 TGD counterpars of blackholes

In TGD based on ZEO the description of the TGD counterpart of blackhole looks different.

1. The TGD counterpart of blackhole is described by zero energy state to which one can assign a causal diamond (CD). At embedding space level of CD is very much like horizon since the induced metric is degenerate. The region outside CD is like Rindler wedge for $M^2 \subset M^4$. For sub-CDs these wedges would look natural and gravitational field could correspond to that created by sub-CD. Therefore it seems that horizons are obtained both at embedding space level and space-time level.

2. Wormhole throats are counterparts of black hole like states at space-time level. Blackhole horizon is replaced by horizon at which the induced metric becomes Euclidian. This horizon is also a causal horizon: nothing leaks from the interior since 4-metric becomes degenerate at the horizon. One cannot anymore apply Rindler wedge argument at the horizon and the argument that Alice sees a state in which blackhole interior and distant observer are maximally entangled is lost. One gets rid of firewall paradox since one does not anymore have maximal entanglement of same system B with two different systems.

3. Strong form of holography holds true. Partonic 2-surfaces and their 4-D tangent space data (string world sheets) code for physics. Generalized blackhole horizon can be said to carry the matter. Particles can condense around horizon (see `http://tinyurl.com/y89xp4bu`). Elementary particles correspond to structures involving wormhole contacts connected by Minkowskian magnetic flux tubes at parallel space-time sheets and combining to form a closed magnetic flux tube. The wormhole contact at the second end of the flux tube can attach to the horizon. This gives rise to a real firewall [K22], and the simplest model for blackhole would be as this kind of hollow spherical structure. The topology of Euclidian region can be more complex than that of the interior of sphere since wormhole flux tubes with Minkowskian signature can be present in interior.

4. The interior of the ordinary blackhole can be isolated from the external world. In TGD framework one cannot assume this. Magnetic flux tubes can connect the wormhole contacts associated with particles very near to horizon and horizon itself to distant system. Gravitational and also other interactions are mediated along this kind of flux tubes and make possible for black hole to exchange energy with external world. At the microscopic level the description in the case of fermions (right handed neutrino is an exception) reduces to string world sheets at which the fermionic modes are localized [K12] by very general arguments. Hence the analog of AdS/CFT duality is realized.

5. The exterior of TGD counterpart of genuine blackhole like in general relativity apart from embedding to $M^4 \times CP_2$. Also the interior of blackhole allows embedding down to some critical radius. At horizon, where $g_{tt} = 1/g_{rr} = 0$ holds true, a small deformation of g_{rr} makes the horizon a light-like surface and 4-metric degenerate. Hence it is natural to assume that blackhole interior has Euclidian metric in TGD framework. In the simplest case matter resides very near to the causal horizon which is now light-like 3-surface at which space-time surface is effectively 3-dimensional metrically. Approximation by Minkowskian physics certainly fails at horizon and below it. The argument leading to firewall paradox is lost.

6. In TGD framework evolution by quantum jumps realized as state function reductions is a key element of quantal evolution. Also blackhole evolution takes place as a sequence of quantum jumps between zero energy states assignable to light-like boundaries of causal

diamond (CD) accompanying blackhole. Therefore loss of information is not a problem. TGD view about quantum jump leads to a rather radical revision of views about the relationship between geometric time and experienced time as well as about the notion of arrow of time already characterizing zero energy states in the sense that positive/negative energy state at upper/lower boundary of CD is prepared and the state at opposite boundary is superposition of states with different particle numbers and ill defined single particle quantum numbers.

7. Density matrix is replaced by M-matrix defined as a product of a hermitian square root of density matrix and unitary S-matrix. One can say that TGD is square root of thermodynamics. The series of state function reductions thermalizes ensembles and now subsystems defined by sub-CDs become thermal ensemble. CD itself can be said to evolve unitarily at the level of U-matrix. If density matrix is projection operator, then maximal entanglement is obtained between positive and negative energy states.

9.4.2 What blackholes could be in TGD Universe?

The first question is what blackholes in TGD are. One can consider this question at level of pure TGD and at the GRT limit of TGD for which space-time metric in standard Minkowski coordinates is obtained as sum of Minkowski metric and deviations of the metrics of space-time sheets from M^4 metric having non-empty projection to the M^4 region considered. This picture fails when one cannot represent space-time surface as graph of a map from M^4 to CP_2.

1. Cosmic strings dominating during primordial cosmology are objects of this kind and the transition from cosmic string dominated cosmology to radiation dominated one corresponds to the analog of inflationary period in TGD.

2. Also the CP_2 type vacuum extremals and their deformations representing lines of generalized Feynman diagrams fail to have description in terms of GRT unless one allows generalization of GRT allowing also Euclidian signature of space-time metric. CP_2 indeed represents a solution of Einstein-Maxwell equations with cosmological constant determined by CP_2 size scale. The natural microscopic counterparts of blackholes in TGD Universe would the lines of generalized Feynman diagrams for which the projection of deformed CP_2 type extremal has astrophysical size so that blackhole would be very much like elementary particle.

The notion of gravitational Planck constant h_{gr} inspired by the work of Nottale and identical with h_{eff} inspired by the findings of bio-electromagnetism is what distinguishes quantum TGD sharply from other theories of quantum gravitation where Planck constant has its ordinary value.

1. The proposal is that the value of $h_{eff} = h_{gr}$ equals to the sheets of the effective covering of embedding space allowing to represent preferred extremals connecting space-like 3-surfaces at the ends of causal diamond and having same Kähler action and possibly also conserved classical isometry charges. This is essentially sub-manifold gravity. Furthermore, second quantization occurs for these multi-furcations in the sense that one can speak of many particle states having discrete wave function in the set of branches of the multi-furcation.

   h_{gr} can be assigned with the magnetic flux tube connecting two massive objects with masses M and m and Equivalence Principle implies the general formula $\hbar_{gr} = GMm/v_0$, where v_0 is a characteristic rotational velocity scale associated with the two-particle system.

2. Notice that similar formula is expected to hold true for the flux tubes mediating other interactions so that for electromagnetic interaction one would have $h_{eff} = h_{em} = Z_1 Z_1 e^2/v_0$. The formula could make sense even for color interaction. Since the generic dimensionless coupling $\alpha_g = g^2/4\pi h_{eff}$ is inversely proportional to h_{eff}, this implies that perturbation theory converges in this phase. $h_{eff}/h \geq 1$ follows if one assumes the quantization rule $h_{eff} = nh$ so that the transition to dark matter phase would occur only when perturbation theory fails.

   Plasma phase would be excellent candidate for a system where strong electromagnetic interaction between highly charged plasma regions leads to the formation of dark matter. The finding of Pollack that the irration of water bounded by gel phase leads to a formations of negatively charged exclusion zones with positive charge outside would be a good example of the phenomenon. h_{em} would be proportional to the square of the total charged generated in exclusion zone. h_{gr} for the pair of systems involved would be product of their masses.

3. The Universal value for gravitational Compton length is given by GM/v_0 and does not depend on the mass of the test particles. This realizes Equivalence Principle and implies quantum coherence in the sense that one obtains same result by applying the Bohr quantization rules to elementary particles forming the system or to the entire system. Gravitational interaction is clearly optimal for macroscopic quantum coherence.

4. Since the velocity parameter satisfies $v_0/c < 1$, the Compton length is larger than Schwartschild radius for $v_0 > 1/\sqrt{2}$ so that quantal effects would make themselves visible even above the Schwartschild radius. Clearly, it might be more appropriate to identify gravitational quantum Compton length as the scale in which quantum gravitation becomes important. It also seems that the notion of blackhole must be replaced with quantum gravitational object with this radius. For instance, Earth's radius is roughly twice the gravitational Compton length for Earth-Sun system.

   For Sun the assumption that v_0 corresponds to the rotation velocity of the particle at the surface of Sun implies that the radius at which transition to quantum phase occurs equals roughly to the radius of solar core inside which nuclear fusion takes place.

Blackholes are characterized by temperature and entropy. Zero energy ontology leads to the idea about quantum TGD as square root of thermo- dynamics and suggests strongly that even ordinary temperature and entropy have space-time correlates.The fact that M-matrices are products of unitary S-matrices and hermitian square roots of density matrices, supports this guess. Square roots of Boltzmann weights involving a phase factor could provide a simple phenomenological description of cell membrane as Josephson junction [K4] having ordinary thermodynamical description as limit.

If there indeed is a connection with ordinary thermodynamics, one expects that TGD counterpart of blackhole evaporation corresponds to ordinary thermal radiation. Gravitational radiation would escape along massless extremals glued to (gravi)- magnetic flux tubes connecting the stellar objects to environment. Em radiation should escape along magnetic flux tubes with Planck constant equal to h_{em}. The geometric differences between the flux tubes would be reflected by the value of n.

9.4.3 Could TGD counterparts of blackholes evaporate?

Could TGD counterparts of blackholes evaporate? The above summary written years after what follows in the sequel already answers this question affirmatively. The following discussion gives a different point without mentioning h_{gr}.

1. One could see the most general TGD counterparts of blackholes as ordinary macroscopic bodies with the space-time sheet representing the object having Euclidian signature of metric in the space-time region defined by the body. As noticed, this region can be topologically a sphere with handles represented as Minkowskian wormholes connecting separate parts of spherical horizon. Therefore the analog of thermal radiation would make sense. Hawking evaporation poses much stronger condition. Elementary particles represent limiting cases of Euclidian regions and electron is stable against decays and also against evaporation of this kind. General TGD blackholes need not have any special gravitational properties. In the case of genuinely blackhole like states, one can also restrict the situation so that the exterior metric is Reissner-Nordström vacuum in good approximation.

2. An attractive manner to interpret Hawking evaporation in the standard framework is by approximating the horizon by Rindler horizon. This leads the study of effectively 2-D Rindler wedge in Minkowski space assignable to accelerated system. The two sides of the wedge correspond to their own Rindler vacua and Minkowski vacuum is sum over pairs of states at both sides so that one obtains thermal spectrum of particle states with Unruh temperature. Accelerated observer would be continually boosted so that the hyperbolic angle η would grow. Accelerated observer would see Hawking radiation.

Does it make sense to speak about accelerated observers at fundamental level? The following little argument suggests that one cannot speak about Hawking radiation at horizon. This conforms with the intuitive idea that Hawking radiation is created outside the horizon.

1. One can assign to each point of space-time surface a generalization of acceleration vector as M^4 part of the trace of second fundamental form. For preferred extremals the trace of the second fundamental form would actually vanish since they are minimal surfaces.

   One can also consider second fundamental form for curves - say geodesics. This has both M^4 and CP_2 parts and does not vanish in general. The orbit of the boundary of string world sheet along light-like 3-surface is one possible identification. Braid strands, which can be both time-like and space-like, could be seen as analogs of accelerated observers with acceleration defined by M^k. The decomposition $M^4 = M^2 \times E^2$ with Rindler coordinates and Rindler decomposition of the M^4 vacuum at each point of the curve would give one further function for $M^2 \subset M^4$ dictated by several general arguments.

2. At the horizon of TGD blackhole the metric changes to Euclidian. Also the dimension of M^4 projection becomes at most $D = 3$ if the proposed

   general solution ansatz for preferred extremals is correct [K12]. Hence the description as Rindler horizon and the approximation by M^4 QFT fails at and below the horizon. This is counterpart for the firewall. This holds true for all braid strands defining orbits along wormhole throats. For space-like string curves situation is different but now a tachyon would be in question. Hence one cannot speak about Unruh radiation and Hawking radiation at horizons and below them.

Could one generalize the notion of hologram from wormhole orbit so that Hawking radiation would result as Unruh radiation? This is possible to imagine.

1. One can consider a slicing of space-time sheet by "parallel" light-like 3-surfaces in the vicinity of given wormhole throat. If it is possible to make measurements at these light-like 3-surfaces, one could have QFT in M^4 as an approximation and have Rindler decomposition, Unruh effect, and Hawking radiation beyond Schwarzschild radius r_s.

2. In WCW geometry strong form of GCI implying strong form of holography suggests that any choice of light-like 3-surface in a slicing of space-time sheet by light-like 3-surfaces is equally goo, and means only a transformation of the Kähler function of WCW by adding to it a real part of holomorphic function induced gauge transformation of Kähler gauge potential of WCW . This does not affect WCW metric and should not affect physics either. Wormhole throats would be of course in a preferred position physically.

3. More precisely, at the wormhole throat the vacuum state is right Rindler vacuum R. At larger distances Minkowski vacuum makes sense approximately and is in reasonable approximation expressible as a sum over tensor products of states of R and L, and both L and R have thermal density matrix resulting in tracing with acceleration defining the Unruh temperature given by the trace of the second fundamental form for the curve (geodesic in question) [B4, B5]. At very small distances from wormhole throat QFT approximation works only for very high energies at the left hand side.

Final remark: I have suggested a p-adic version of Hawking-Bekenstein formula holding true at elementary particle level [K20]. Maybe p-adic thermodynamics could replace blackhole thermodynamics in the case of elementary particles at least.

The conclusion is that blackhole and blackhole evaporation have TGD based generalization. The notion of blackhole like state would be very general and can be assigned with any physical system with a well-defined geometric shape (defined by the Euclidian space-time sheet). Gravitational blackholes would be only special cases. The notion of Hawking radiation identified as Unruh radiation could also make sense, and one could understand Rindler coordinates in terms of $M^2 \subset M^4$ decomposition central for quantum TGD. It is however essential that the acceleration parameter characterizing this radiation is defined by the trace of second fundamental form in the embedding space: here GRT approach can be criticized of internal inconsistency. Since the interior of any TGD blackhole is Euclidian - this is absolutely essential- the argument leading to the firewall paradox fails. Horizon is in TGD framework a genuine firewall but this does not mean a failure of Equivalence Principle which only says only that Einstein's equations hold true for preferred extremals: Minkowskian QFT is always a good local approximation. A further important notion is astroscopic quantum coherence characterized by h_{gr}. Quantum gravitational Compton length GM/v_0, v_0 the rotational velocity of astrophysical object suggests itself as a proper parameter characteristizing the boundary quantum gravitational realm.

10 New View About Black-Holes

In TGD framework the embedding of the interior metric of ordinary black-holes fails and there is a good argument suggesting that horizon is transformed to a "partonic" light-like 3-surface at which the signature of the induced metric changes [K29]. Black-hole would be replaced by a gigantic particle having no electro-weak interactions since the state would be created using super-symplectic generators and generate its mass via p-adic thermodynamics. Schwartschild radius equals to Compton length if the generalization of Nottale formula for Planck constant holds true. Super-symplectic black-holes behave as dark matter and are very natural final states of the star and follow naturally neutron star phase. Also a microscopic description of black-hole as a gigantic hadron emerges. $\mathcal{N}=\infty$ SUSY formulated in [K17] is a good candidate for the formulation of a first principle theory for the description of the anyonic state.

10.1 Anyonic View About Blackholes

A new element to the model of black hole comes from the vision that black hole horizon as a light-like 3-surface corresponds to a light-like orbit of light-like partonic 2-surface. This allows two kinds of black holes. Fermion like black hole would correspond to a deformed CP_2 type extremal which Euclidian signature of metric and topologically condensed at a space-time sheet with a Minkowskian signature. Boson like black hole would correspond to a large wormhole contact connecting two space-time sheets with Minkowskian signature. Wormhole contact would be a piece deformed CP_2 type extremal possessing two light-like throats defining two black hole horizons very near to each other. It does not seem absolutely necessary to assume that the interior metric of the black-hole is realized in another space-time sheet with Minkowskian signature.

Second new element relates to the value of Planck constant. For $\hbar_{gr} = 4GM^2$ the Planck length $L_P(\hbar) = \sqrt{\hbar G}$ equals to Schwartschild radius and Planck mass equals to $M_P(\hbar) = \sqrt{\hbar/G} = 2M$. If the mass of the system is below the ordinary Planck mass: $M \leq m_P(\hbar_0)/2 = \sqrt{\hbar_0/4G}$, gravitational Planck constant would be smaller than the ordinary Planck constant. If only coverings are allowed -as is the case if the hierarchy of Planck constants follows from basic TGD- these values of Planck constant are not possible.

Blackhole surface contains ultra dense matter so that perturbation theory is not expected to converge for the standard value of Planck constant but do so for gravitational Planck constant. If the phase transition increasing Planck constant is a friendly gesture of Nature making perturbation theory convergent, one expects that only the black holes for which Planck constant is such that $GM^2/4\pi\hbar < 1$ holds true are formed. Black hole entropy for given sheet of the covering -being proportional to $1/\hbar$- is of order unity so that TGD black holes are not very entropic. The entire blackhole entropy is just the standard black hole entropy since there are $\hbar/\hbar_0$ sheets in the covering. This would suggest that entropy serves as a control variable in the sense that when it exceeds the threshold value, the partonic 2-surfaces at the ends of CD split to a surfaces in the covering.

The model of anyons and fractional quantum Hall effect [K22] leads to the conclusion that various charges are fractionized so that a partonic 2-surface possessing given charges splits in the interior of space-time surface to n_an_b components with same fractional charge $1/n_an_b$. The ends of space-time sheet split to n_b components with charges coming as multiples of $1/n_b$ and wormholes to n_a components with charges coming as multiples of $1/n_a$. In CD degrees of freedom fractionization can occur only if the partonic 2-surface enloses the tip of CD. This would mean spin fractionization.

If the partonic 2-surface surrounds the tip of causal diamond CD, the matter at its surface is in anyonic state with fractional M^4 charges and CP_2. Otherwise only CP_2 charges are fractional.

Anyonic black hole can be seen as single gigantic elementary particle stabilized by fractional quantum numbers of the constituents preventing them from escaping from the system and transforming to ordinary visible matter. For F-C option a huge number of different black holes are possible for a given value of $\hbar$ since there is infinite variety of pairs (n_a, n_b) of integers giving rise to same value of $\hbar$. For C-C option possibly - which possibly reduces to the basic quantum TGD - the number of black holes corresponds to the number of decompositions of $n = n_a n_b$ to a product.

One can imagine that the partonic surface is not exact sphere except for ideal black holes but contains large number of magnetic flux tubes giving rise to handles. Also a pair of spheres with different radii can be considered with surfaces of spheres connected by braided flux tubes. The braiding of these handles can represent information and one can even consider the possibility that black hole can act as a topological quantum computer. There would be no sharp difference between the dark parts of black holes and those of ordinary stars. Only the volume containing the complex flux tube structures associated with the orbits of planets and various objects around star would become very small for black hole so that the black hole might code for the topological information of the matter collapsed into it.

10.2 Super-Symplectic Bosons

TGD predicts also exotic bosons which are analogous to fermion in the sense that they correspond to single wormhole throat associated with CP_2 type vacuum extremal whereas ordinary gauge bosons corresponds to a pair of wormhole contacts assignable to wormhole contact connecting positive and negative energy space-time sheets. These bosons have super-conformal partners with quantum numbers of right handed neutrino and thus having no electro-weak couplings. The bosons are created by the purely bosonic part of super-symplectic algebra [K3, K12], whose generators belong to the representations of the color group and 3-D rotation group but have vanishing electro-weak quantum numbers. Their spin is analogous to orbital angular momentum whereas the spin of ordinary gauge bosons reduces to fermionic spin. Recall that super-symplectic algebra is crucial for the construction of WCW Kähler geometry. If one assumes that super-symplectic gluons suffer topological mixing identical with that suffered by say U type quarks, the conformal weights would be (5, 6, 58) for the three lowest generations. The application of super-symplectic bosons in TGD based model of hadron masses is discussed in [K10] and here only a brief summary is given.

As explained in [K10], the assignment of these bosons to hadronic space-time sheet is an attractive idea.

1. Quarks explain only a small fraction of the baryon mass and that there is an additional contribution which in a good approximation does not depend on baryon. This contribution should correspond to the non-perturbative aspects of QCD. A possible identification of this contribution is in terms of super-symplectic gluons. Baryonic space-time sheet with $k = 107$ would contain a many-particle state of super-symplectic gluons with net conformal weight of 16 units. This leads to a model of baryons masses in which masses are predicted with an accuracy better than 1 per cent [K8].

2. Hadronic string model provides a phenomenological description of non-perturbative aspects of QCD and a connection with the hadronic string model indeed emerges. Hadronic string tension is predicted correctly from the additivity of mass squared for $J = 2$ bound states of super-symplectic quanta. If the topological mixing for super-symplectic bosons is equal to that for U type quarks then a 3-particle state formed by 2 super-symplectic quanta from the first generation and 1 quantum from the second generation would define baryonic ground state with 16 units of conformal weight. A very precise prediction for hadron masses results by assuming that the spin of hadron correlates with its super-symplectic particle content.

3. Also the baryonic spin puzzle caused by the fact that quarks give only a small contribution to the spin of baryons, could find a natural solution since these bosons could give to the spin of baryon an angular momentum like contribution having nothing to do with the angular momentum of quarks.

4. Super-symplectic bosons suggest a solution to several other anomalies related to hadron physics. The events observed for a couple of years ago in RHIC [?] suggest a creation of

a black-hole like state in the collision of heavy nuclei and inspire the notion of color glass condensate of gluons, whose natural identification in TGD framework would be in terms of a fusion of hadronic space-time sheets containing super-symplectic matter materialized also from the collision energy. In the collision, valence quarks connected together by color bonds to form separate units would evaporate from their hadronic space-time sheets in the collision, and would define TGD counterpart of Pomeron, which experienced a reincarnation for few years ago [?]. The strange features of the events related to the collisions of high energy cosmic rays with hadrons of atmosphere (the particles in question are hadron like but the penetration length is anomalously long and the rate for the production of hadrons increases as one approaches surface of Earth) could be also understood in terms of the same general mechanism.

5. RHIC events have features which suggest that color glass condensate is very much analogous to a black-hole. This analogy has a precise formulation. Super-symplectic matter has no electro-weak interactions and is therefore dark matter in a strict sense. The exchange of super-symplectic $J = 2$ quanta brings in gravitation and string mass formula holds true. The value of the gravitational constant is however determined by hadronic p-adic length scale rather than CP_2 length scale so that strong gravitation is in question. This picture leads naturally to the question whether ordinary black-holes should be replaced by super-symplectic black-holes in TGD Universe as a natural final step of stellar evolution after the neutron star phase during which star already behaving like a gigantic hadron in super-symplectic degrees of freedom.

10.3 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 [K9].

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. "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

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) \ , \tag{10.1}$$

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

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2 . \tag{10.2}$$

Here one has $m(CP_2) = \hbar_0/R$, R the length of the geodesic of CP_2.

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

$$S = \frac{A}{4G\hbar} = \frac{\pi G M^2}{\hbar} . \tag{10.3}$$

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 [K29] 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. For large values of $\hbar$ the Hawking-Bekenstein entropy becomes very small.

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 [K23] 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

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 , \quad v_0 = 1/2 . \tag{10.4}$$

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 [K23]. Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

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

For $\hbar_{gr} = GM^2/v_0$ assignable to binary star with identical masses and for $v_0 = 1/2$ the black-hole entropy for an ideal dark black-hole would be

$$S = \pi \tag{10.5}$$

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.

10.4 Blackholes do not absorb dark matter so fast as they should

Astronomers claim that blackholes do not absorb dark matter as fast as they should [E25] (see the popular article at `http://tinyurl.com/h6pjxpn` and article at `http://tinyurl.com/ybqzbzhz`). The claim is based on a model for dark matter: if the absorption rate were what one would expect by identifying dark matter as some exotic particle, the rate would be quite too fast and the Universe would look very different.

How could this relate to the vision that dark matter is ordinary matter in large Planck constant phase with $h_{eff} = n \times h = h_{gr} = GMm/v_0$ proposed to be generated at quantum criticality [K15]? Gravitational Planck constant h_{gr} was originally introduced by Nottale [E15]. In this formula M is some mass, say that of black hole or astrophysical object, m is much smaller mass, say that of elementary particle, and v_0 is velocity parameter, which is assumed to be in constant ratio to the spinning velocity of M in the model for quantum biology explaining biophotons as decay products of dark cyclotron photons.

Could the large value of Planck constant force dark matter be delocalized in much longer scale than blackhole size and in this manner imply that the absorption of dark matter by blackhole is not a sensible notion unless dark matter is transformed to ordinary matter? Could it be that the transformation does not occur at all or occurs very slowly and is therefore the slow bottle neck step in the process leading to the absorption to the interior of the blackhole? This could be the case! The dark Compton length would be $\Lambda_{gr} = h_{gr}/m = GM/v_0 = r_S/2v_0$, and for $v_0/c << 1$ this would give dark Compton wavelength considerable larger than the radius $r_S = 2GM$ of blackhole. Note that dark Compton length would not depend on m in accordance with Equivalence Principle and natural if one accepts gravitational quantum coherence is astrophysical scales. The observation would thus suggest that dark matter around blackhole is stable against phase transition to ordinary matter or the transition takes place very slowly. This in turn would reflect Negentropy Maximization Principle favoring the generation of entanglement negentropy assignable to dark matter.

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