# Quantum Astrophysics

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# Contents

**Abstract**

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.

Since space-time surfaces are 4-surfaces in $H = M^4 \times CP_2$, Bohr rules can be formulated in a manner 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 the symmetry of field bodies associated with the structure in question. One can say that orbit becomes particle at the level of dark matter. Circles and spokes representing the dark matter structures, gravi-electric flux quanta, and also circles representing gravi-magnetic flux tubes orthogonal to the quantization plane become basic building blocks of dark matter structures. Simplest of them are rings and cart-wheel like structures. The subgroups of $Z_n$ can act as approximate symmetries of visible matter and if one accepts ruler-and-compass hypothesis very powerful predictions follow.

Concerning Bohr orbitology in astrophysical length scales, the basic observation is that in the case of a straight cosmic string creating a gravitational potential of form $v_1^2/\rho$ 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 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 for dark matter and in the first approximation one could neglect the intermediate stages.

This general picture is applied by considering some simple models for astrophysical systems involving planar structures. There are several universal predictions. Velocity spectrum is universal and only the Bohr radii depend on the choice of mass distribution. The inclusion of cosmic string implies that the system associated with the central mass is finite. Quite generally dark parts of astrophysical objects have shell like structure like atoms as do also ring like structures.

p-Adic length scale hypothesis provides a manner to obtain a realistic model for the central objects meaning a structure consisting of shells coming as half octaves of the basic radius: this obviously relates to Titius-Bode law. Also a simple model for planetary rings is obtained. Bohr orbits do not follow cosmic expansion which is obtained only in the average sense if phase transitions reducing the value of basic parameter $v_0$ occur at preferred values of cosmic time. This explains why $v_0$ has different values and also the decomposition of planetary system to outer and inner planets with different values of $v_0$.

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. 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 the description in terms of classical chaos 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.

# 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 [23] 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 [18] 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 [A9] 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 [D6].

## 1.1 Generalization of the notion of imbedding space

Quite generally, the hierarchy of Planck constant is realized by generalizing the notion of imbedding space such that one has a book like structure with various almost-copies of imbedding 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 Original view about generalized imbedding space

The original generalization of the imbedding space was too restricted and the belief that the proposed generalization of the imbedding space could explain naturally phenomena like quantum Hall effect involving fractionization of quantum numbers like spin and charge turned out to be wrong. The idea was that a given page of the book like structure would correspond to an orbifold obtained from $H = M^4 \times CP_2$ by identifying the points of $H$ obtained from each other by the action of group $G_a \times G_b$, where the factors act in $M^4$ and $CP_2$ degrees of freedom. As a matter fact, this identification implies just the opposite of fractionization if these quantum numbers are assigned with the symmetries of the imbedding space. For instance, quantization unit for orbital angular momentum becomes $n_a$ where $Z_{n_a}$ is the maximal cyclic subgroup of $G_a$.

One can however imagine of obtaining fractionization at the level of imbedding space for space-time sheets, which are analogous to multi-sheeted Riemann surfaces (say Riemann surfaces associated with $z^{1/n}$ since the rotation by $2\pi$ understood as a homotopy of $M^4$ lifted to the space-time sheet is a non-closed curve. Continuity requirement indeed allows fractionization of the orbital quantum numbers and color in this kind of situation.

### 1.1.2 Extension of imbedding space by allowing coverings

This means an extension of the imbedding space by allowing also $G_a$ *resp.* $G_b$-fold coverings of $\hat{M}^2 = M^4\backslash M^2$ *resp.* $\hat{CP}_2 = CP_2\backslash S^2$, where $M^2$ 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 $M^4 \times S^2$ and $M^2 \times CP_2$ which correspond to quantum criticality. The extreme form of quantum criticality corresponds to leakage through $M^2 \times S^2$.

The book has four kinds of pages:

1) $[\hat{M}^4/G_a] \times [\hat{CP}_2/G_b]$ with Planck constant $\hbar/\hbar_0 = n_a/n_b$: $n_i$ is the order of maximal cyclic subgroup of $G_i$. Only these pages were included in the original "book": the problem concerning biological applications is that large values of Planck constant require high rotational symmetries;

2) $[\hat{M}^4" \times "G_a] \times [\hat{CP}_2/G_b]$ with $\hbar/\hbar_0 = 1/(n_a n_b)$: " $\times$ "$G_i$ refers to $G_i$ covering. Note that Planck constant is always smaller than its standard value

$\hbar_0$ ($n_a = n_b = 1$) in this case implying for instance that the binding energy scale of hydrogen atom is scaled up;

3) $[\hat{M}^4" \times "G_a] \times [\hat{CP}_2" \times "G_b]$ with $\hbar/\hbar_0 = n_b/n_a$;

4) $[\hat{M}^4/G_a] \times [\hat{CP}_2" \times "G_b]$ with $\hbar/\hbar_0 = n_a n_b$; note that in this case the Planck constant is maximal.

The pages of type 4) are the most promising candidates concerning the understanding of living matter. They are also highly interesting from the point of view of astrophysics.

$G_a$ symmetry is implied in $M^4$ degrees of freedom since the restriction to the orbifold $\hat{M}^4/G_a$ is equivalent to the $G_a$-invariance of quantum states. Molecular rotational symmetries correspond typically to small groups $G_a$ $G_a = Z_n$, $n = 5, 6$ are favored for molecules containing aromatic cycles. Also genuinely 3-dimensional tedrahedral, octahedral, and icosahedral symmetries appear in living matter. Also astrophysical systems could possess small $G_a$ as symmetries and the hexagonal structure at the North Pole of Saturn could be an example of $n_a = 6$ fold symmetry. $n_b$ would in this case be extremely large.

## 1.2 Gravitational Bohr orbitology

Since space-time surfaces are 4-surfaces in $H = M^4 \times CP_2$, Bohr rules can be formulated in a manner 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 the symmetry of field bodies associated with the structure in question.

The original generalization of the imbedding space was yet not general enough and assigned $Z_n$ to $M^4$ degrees of freedom but as already explained (see also Appendix) later a generalization emerged which allowed to assign $Z_n$ with large $n$ to $CP_2$ degrees of freedom. Hence obtains dark matter symmetries with small discrete symmetry group in $M^4$ degrees of freedom and large symmetry group in $CP_2$ degrees of freedom and hence also large value of Planck constant equal to $n_a n_b$ where $n_i$ is the order of the maximal cyclic subgroup of $G_i$, $i = a, b$ corresponding to $M^4$ and $CP_2$ degrees of freedom.

One can say that orbit becomes particle at the level of dark matter. Circles and spokes representing the dark matter structures, gravi-electric flux quanta, and also circles representing gravi-magnetic flux tubes orthogonal to the quantization plane become basic building blocks of dark matter structures. Simplest of them are rings and cart-wheel like structures with rather small symmetry groups. For large values of $n_a$ the subgroups of $Z_{n_a}$ acting as rotational symmetries symmetries of magnetic body can act as approximate symmetries of the visible matter and if one accepts ruler-and-compass hypothesis powerful predictions follow. On the other hand, $n_a$ can be also small and correspond to symmetries of visible matter in astrophysical scales (say the hexagonal structure associated with Saturnus) provided the full generalization of imbedding space discussed in Appendix is accepted.

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 [16]. 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 $M^4$ orbifold structure and large value of $n_b$ characterizing $CP_2$ covering.

The planetary Bohr orbitology has been already discussed in the chapter "TGD and Astrophysics" [D6] with applications solar system and exo-planets. This discussion is not based on the full generalization of the imbedding space but the general results are not changed appreciably 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.

# 2 Basic objections against planetary Bohr orbitology

There are two objections against planetary Bohr orbitology.

1. The success of this approach in the case solar system [D6] is not enough. In particular, it requires different values of $v_0$ for inner and outer planets.

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

## 2.1 Also exoplanets obey Bohr rules

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).

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.

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 $v_0 \rightarrow (16/15) \times v_0$ and $v_0 \rightarrow 2 \times v_0$).

There is a further objection. 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 $v_0 \rightarrow v_0/20$ giving $r_0 \simeq 1.2R_E$. 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 [22] discussed in the last section of [D6] support the prediction that planetary system does not participate cosmic expansion in a smooth manner.

## 2.2 How General Coordinate Invariance and Lorentz invariance are achieved?

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, imbedding 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 $\Phi_{gr}$ 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.

### 2.2.1 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

$$m\oint v \bullet dl \quad = \quad n \times hbar_{gr} \quad . \tag{1}$$

The condition reduces to the condition on velocity circulation

$$\oint v \bullet dl \quad = \quad n \times \frac{GM}{v_0} \quad . \tag{2}$$

In simple systems with circular rings forced by $Z_n$ symmetry 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.

$Z_n$ symmetry seems to imply that only circular orbits need to be considered and 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 with $Z_n$ symmetry and dark matter rings could suffer partial or complete phase transition to visible matter. Note however that radial $Z_n$ symmetry allows also cart-wheel like structures with radial spokes which correspond to $n = 0$ Bohr orbits.

### 2.2.2 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

$$\oint (v - A_{gr}) \bullet dl. \tag{3}$$

Here one must notice that dark matter ring is $Z_n$ symmetric and closed so that the geodesic motion of visible matter cannot correspond strictly to the dark matter ring (perihelion shift of Mercury). Just by passing notice that the presence of dark matter ring can explain also the complex braidings associated with the planetary rings.

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

$$GM \rightarrow \oint e \bullet r^2 E_{gr} \times dl . \quad (4)$$

$e$ 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.

#### 2.2.3 Rings and spokes as the basic building blocks of dark matter structures

The Bohr orbit model for the planetary orbits based on the hierarchy of dark matter relies in an essential manner on the idea that macroscopic quantum phases of dark matter dictate to a high degree the behavior of the visible matter. Dark matter is concentrated on closed classical orbits in the simple rotationally symmetric gravitational potentials involved. Orbits become basic structures instead of points at the level of dark matter. There are two options to consider. Reader can

1. If dark matter sector of the generalized imbedding space $H$ (visualizable as a page of a book) corresponds to $[\hat{M}^4/G_a] \times [\hat{CP}_2/G_b]$ giving Planck constant $\hbar/\hbar_0 = n_a/n_b$, a discrete subgroup $Z_{n_a}$ of rotational group with a very large value of $n_a$ characterizes dark matter structures quite generally. This group could be interpreted as symmetries of gravitational field body. At the level of visible matter this symmetry can be broken to an approximate symmetry defined by some subgroup of $Z_{n_a}$.

2. If the dark matter sector of the generalized imbedding space $H$ (see Appendix) corresponds to $[\hat{M}^4/G_a] \times [\hat{CP}_2" \times "G_b]$, where "$\times$" refers to $G_b$-covering of $CP_2$ giving Planck constant $\hbar/\hbar_0 = n_a \times n_b$. $n_a$ can be small if $n_b$ is very large and $n_a$ can directly correspond to a symmetry group of dark matter and therefore to an approximate symmetry group of visible matter. The hexagon at the North pole of Saturn is one possible example of this situation.

Circles and radial spokes are the basic Platonic building blocks of dark matter structures. The interpretation of spokes would be as (gravi-)electric flux tubes. Radial spokes correspond to $n = 0$ states in Bohr quantization for hydrogen atom and orbits ending into atom. Spokes have been observed in planetary rings besides decomposition to narrow rings and also in the galactic scale [25]. Also flux tubes of (gravi-)magnetic fields with $Z_n$ symmetry define rotational symmetric structures analogous to quantized dipole fields.

Gravi-magnetic flux tubes indeed correspond to circles rather than field lines of a dipole field for the simplest model of gravi-magnetic field, which means deviation from GRT predictions for gravi-magnetic torque on gyroscope outside equator: unfortunately the recent experiments are performed at equator. The flux tubes be seen only as circles orthogonal to the preferred plane and planetary Bohr rules apply automatically also now.

A word of worry is in order here. Ellipses are very natural objects in Bohr orbitology and for a given value of n would give $n^2 - 1$ additional orbits. In planetary situation they would have very large eccentricities and are not realized. Comets can have closed highly eccentric orbits and correspond to large values of $n$. In any case, one is forced to ask whether the exactly $Z_n$ symmetric objects are too Platonic creatures to live in the harsh real world. Should one at least generalize the definition of the action of $Z_n$ as symmetry so that it could rotate the points of ellipse to each other. This might make sense. In the case of dark matter ellipses the radial spokes with $Z_n$ symmetry representing radial gravito-electric flux quanta would still connect dark matter ellipse to the central object and the rotation of the spoke structure induces a unique rotation of points at ellipse.

# 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 $v_1^2/\rho$ 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 [D5] 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 $n$ return flux tubes, $n$ very large in accordance with the $Z_n$ symmetry for the dark matter but also in this case the situation in the nearby region remains the same. 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 the breaking of the rotational symmetry down to a discrete $Z_n$ symmetry and in the presence of the central mass selects 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.

For the visible matter $Z_n$ symmetry can break down to an approximate symmetry corresponding to a subgroup of $Z_m \subset Z_n$, and if one accepts the ruler-and-compass hypothesis for favored values of $n$, very strong prediction that the subgroup corresponds to $m$ which is product of different Fermat primes and power of 2, follows. Simplest $Z_m$ symmetric visible structures would be cart-wheel like structures consisting of rings with spokes. As already noticed $n = n_a$ can be small for the sector $[\hat{M}^4/G_a] \times [\hat{CP}_2" \times "G_b]$ of generalized imbedding space.

## 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

$$\begin{aligned} a &= \frac{v_1^2}{\rho} \ , \\ v_1^2 &= G\frac{dM}{dL} \ . \end{aligned} \tag{5}$$

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

$$u = \frac{1}{\rho} = \frac{v^2 - v_1^2}{GM} \ . \tag{6}$$

### 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 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

$$\frac{d\hbar}{dl} = G \times \frac{m}{2\pi} \times \frac{dM}{dL} \times \frac{1}{v_0} = \frac{m}{2\pi} \times \frac{v_1^2}{v_0} . \tag{7}$$

where $m$ is the mass of dark matter ring. The inclusion of $2\pi$ 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

$$\frac{dm}{dl} \times v\rho = n \times \frac{d\hbar}{dl} = n \times \frac{m}{2\pi} \times \frac{v_1^2}{v_0} . \tag{8}$$

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

$$v = n\frac{v_1^2}{v_0} . \tag{9}$$

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 $\rho$.

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

$$\hbar(string) = m \times \frac{v_1^2}{v_0}\rho . \tag{10}$$

One can say that a length $\rho$ 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

$$v\rho = n\frac{GM + \frac{v_1^2}{v_0}\rho}{v_0} . \tag{11}$$

This gives the quantization condition

$$u = \frac{vv_0 - nv_1^2}{nGM} . \tag{12}$$

### 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

$$x^2 - \frac{x}{n} = 0 \ . \tag{13}$$

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

$$\begin{aligned} \rho(n) &= \frac{n^2}{1-n^2\epsilon^2} \times r_0 \ , \\ r_0 &= \frac{GM}{v_0^2} \ . \end{aligned} \tag{14}$$

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 Could one understand the different values of gravitational Planck constant for inner and outer planetary systems?

The model can be applied also to the solar system. Indeed, a cosmic string in the direction of rotation axis is predicted by the TGD inspired model for the final state of the star (or any astrophysical object [D3]). This string plays an important role in the TGD inspired model for gamma ray bursts from pulsars [D6].

In the simplest Bohr model for the solar system outer planets correspond to a smaller value of $v_0$ than inner planets ($v_0 = 2^{-11} \rightarrow v_0/5$). This is a grave objection against the model [D6].

### 3.2.1 The idea

One might hope that the inclusion of the gravitational force of cosmic string could explain the failure of the Bohr orbit model with single value of $v_0$ and give a physical justification for the modification of the value of $v_0$. Indeed, only a finite number of Bohr orbits are possible in the presence of cosmic string and the radii for large $n \rightarrow \epsilon = v_1/v_0$ become infinite. For $\epsilon = v_1/v_0 = 1/5$ the radius of Earth's orbit with $n = 5$ would be infinite so that $\epsilon$ must be considerably smaller.

One can however consider the possibility that $1/5 > \epsilon > 1/10$ so that only inner planets would be allowed (first outer planet would correspond to $n = 10$ for $v_0$). If this were the case the phase transition reducing the value of $v_0$ to say $v_0/5$ would necessarily occur for the outer planets. Outer planetary system could be seen as a scaled up variant of the inner planetary system. $\epsilon \rightarrow \epsilon/5$ would scale up the upper bound for $n$ by factor 5 and thus the upper bound for the radii of outer planets by factor 25. Note that if some fraction of the flux of cosmic string returns back in some length scale in the region between inner and outer planets $\epsilon$ is further reduced.

### 3.2.2 The failure of the idea in its simplest form

Unfortunately the proposed idea does not survive quantitative tests as such. The presence of an additional acceleration due to the cosmic string means that for circular orbits with a given radius the value of velocity is larger than that predicted by Newton's theory ($v^2 \rightarrow v^2 + v_1^2$). This acceleration can be parameterized as

$$a = \epsilon^2 \times \frac{r_E}{r} \times \frac{v_0^2}{AU} = \epsilon^2 \times (\frac{r_E}{r}) \times .15 \ \ \frac{m}{s^2} \ . \tag{15}$$

In the region between Jupiter and Earth one certainly has $\epsilon < 30$ and this would give $a < 1.7 \times 10^{-4}(r_E/R)$ m/s$^2$.

This would mean the presence of an anomalous inwards radial acceleration $v_1^2/\rho$ directed towards the rotation axis of the solar system. This acceleration is not probably related to the anomalous *constant* acceleration found for spacecrafts [21, D6] and having the value $a = (8.74 \pm 1.33) \times 10^{-10}$ m/s$^2$. This bound is certainly satisfied for the $\epsilon < 2 \times 10^{-4}$.

The bound means that the Bohr orbit model is excellent for $n < 5 \times 10^3$ meaning size scale of order light year (the distance to nearest star is about 4 light years). Hence it would seem that the decomposition to inner and outer planetary systems cannot be due to the impossibly to have outer planets for $v_0 = 2^{-11}$. One must be however be very cautious since this process might have occurred during very early stage of the planetary evolution.

### 3.2.3 How could one modify the idea?

The proposed idea is too beautiful to be given up without fighting.

1. One could imagine that most of the cosmic string flux returns back in the region between inner and outer planets so that the outer planets would

see only a very small cosmic string contribution to the gravitational force but somewhat larger solar mass. Very probably such a large value of the anomalous acceleration for inner planets would have been discovered as anomalously large velocities of the inner planets.

2. According to Masreliez [22] planetary radii seem to be shrinking with a velocity compensating exactly the cosmic expansion velocity. Bohr quantization allows to understand this effect [D6] and it has no connection with the cosmic string contribution to the gravitational force. The $M^4$ radial coordinate is the natural radial coordinate in the Bohr orbit model and the radii of Bohr orbits remain constant so that planetary system does not participate the cosmic expansion. This means that the radii measured in the Robertson-Walker coordinate $r = r_M/a$ appear to shrink.

This raises the possibility that cosmic expansion of the solar system has taken place in average sense involving discrete sequence of phase transitions reducing the value of $\epsilon$. If this were the case, the decomposition to the inner and outer planetary systems might have taken place during the primordial stage. Inner and outer planetary systems could be also imagined to have originated from two separate mass shells emanating from the Sun and expanding via a discrete sequence of phase transitions reducing the value of the cosmic string tension. Part of the return flux and the flux on the rotation axes compensate each other. This could give rise to an emission of closed magnetic flux tubes.

## 3.3 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.

### 3.3.1 Rings of Saturn and Jupiter

The rings of Saturn and Jupiter [19, 20] could be seen a intermediate states in the process leading to the formation of satellites. Both planets indeed possess a large number of satellites [19, 20]. This would suggest that Saturn and Jupiter and outer planets in general are younger than the 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 [23].

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 [18] could be seen as a particular instance of this process.

The $Z_n$ symmetry for the dark matter with very large $n$ citePlanck suggests the possibility of more precise predictions. If $n$ is a ruler-and-compass integer it has as factors only first powers of Fermat primes and a very large power of 2. The breaking of $Z_n$ symmetry at the level of visible matter would naturally occur to subgroups $Z_m \subset Z_n$. Since $m$ is a factor of $n$, the average number of matter clumps could tend to be a factor of $n$, and hence a ruler-and-compass integer. Also the hexagonal symmetry discovered near North Pole of Saturn [17] could have interpretation in terms of this symmetry breaking mechanism.

### 3.3.2 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 [A9] making dark matter a macroscopic quantum phase in astrophysical length and time scales. Rotationally symmetric structures - such as rings- with an exact rotational symmetry $Z_n$, $n = GMm/v_0$ very large, of the "field body" of the system, is the basic prediction. 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, 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 [23].

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 [23] 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 [23]. 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,... If these are found, I would say that the situation is settled.

## 3.4 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 pan-cake of height $L$ and radius $R$. Approximate spherical symmetry suggest $L = 2R$.

The governing conditions are

$$\begin{aligned} v^2(\rho) &= G(dM/dl)(\rho) + v_1^2 \ , \\ v(\rho) &= \frac{v_0}{n} \ . \end{aligned} \tag{16}$$

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.

### 3.4.1 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

$$\begin{aligned} v(\rho) &= \sqrt{GK}(\rho/\rho_0)^{k/2} \ , \\ \omega(\rho) &= \sqrt{GK}(\rho/\rho_0)^{k/2-1} \ , \\ \rho(n) &= \rho_0(v_0/\sqrt{GK})^{2/k} \times n^{-2/k} \ . \end{aligned} \tag{17}$$

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 $\rho$ 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

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

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 [24] 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

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

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

#### 3.4.2 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 [D3]. 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. $v_0 \to v_0/20$ 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 [D6] 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.

## 3.5 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 [34, 35]. 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 $\rho_{min}$ 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 [16]. 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 delocalized 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 has peaks the 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?

### 4.3.1 Quantum criticality

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 imbedding spaces labelled 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 imbedding space allows to formulate this idea in precise manner and each sector of imbedding space is characterized by discrete symmetry groups $Z_n$ acting in $M^4$ and $CP_2$ degrees of freedom. The transition from quantum to classical corresponds to a reduction of $Z_n$ to subgroup $Z_m$, $m$ a factor of $n$. Ruler-and-

compass hypothesis implies very powerful predictions for the remnants of this symmetry at the level of visible matter. Note that the reduction of the symmetry in this chaos-to-order transition!

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.

#### 4.3.2 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.

#### 4.3.3 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 [26]. Remarkably, there is direct evidence for galactic cart-wheels (for pictures of them see [25]). There are also polar ring galaxies consisting of an ordinary galaxy plus ring approximately orthogonal to it and believed to form in galactic collisions [27]. The ring rotating with the ordinary galaxy can be identified in terms of gravi-magnetic flux tube orthogonal to the galactic plane: in this case $Z_n$ symmetry would be completely broken at the level of visible matter.

# 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 [29]. 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

$$P = \frac{dE}{dt} = \frac{32}{\pi}\frac{G^2 M_1 M_2 (M_1+M_2)}{R^5} \ . \quad (18)$$

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 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 [29] 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[29]. 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 Model for dark gravitons

In this subsection models for dark gravitons are discussed.

### 5.2.1 Gravitons in TGD

Unlike the naive 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 modified 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 configuration space 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.

### 5.2.2 What kind of dark gravitons can one consider?

First of all one must decide what sector of the generalized imbedding space dark graviton correspond to. There are four options of which three can give rise to large $\hbar$.

1. $[\hat{M}^4/G_a] \times [\hat{CP}_2/G_b]$ corresponds to Planck constant $\hbar/\hbar_0 = n_a/n_b$ with $n_a$ defining the order of the maximal cyclic subgroup of $G_a$ very large. $G_a$ would be interpreted as the rotational symmetry of the gravitational field body. The unit of angular momentum of the graviton is very large and can be understood in terms of the large value of orbital angular momentum forced by the unit $n_a/n_b$ for angular momentum. The original model was based on this option.

2. $[\hat{M}^4/G_a] \times [\hat{CP_2}" \times "G_b]$ corresponds to Planck constant $\hbar/\hbar_0 = n_a \times n_b$ with $n_b$ very large. This case allows small $n_a$ and $G_a$ could be interpreted as the rotational symmetry of the dark matter. Each sheet of $CP_2$ covering can be thought of carrying one spin 2 graviton plus additional orbital momentum which effectively scales the unit of spin with $n_a$. For $n_a = 1$ large $\hbar$ graviton can be seen as a bunch of ordinary spin 2 gravitons.

3. $[\hat{M}^4" \times "G_a] \times [\hat{CP_2}" \times "G_b]$ corresponds to $\hbar/\hbar_0 = n_b/n_a$ and $n_b$ should be large. One might speak about anyonic graviton.

Only the options a) and b) will be discussed in the sequel.

Once the sector of the generalized imbedding space is selected, one has still two options corresponding to spherical and plane waves. Spherical dark gravitons (or briefly giant gravitons) could be emitted in quantum transitions of say dark gravitational variant of hydrogen atom. Giant graviton is expected to decohere into topological light rays ("MEs"), which are the TGD counterparts of plane waves and define second model for dark graviton. They are expected to be detectable by human built detectors.

For **Option I** the de-coherence of spherically dark graviton would correspond to de-coherence into MEs with large $G_a$ symmetry ($Z_{n_b a}$ or or $Z_{n_a}$ plus reflection) around propagation axis. The de-coherence can continue further. For **Option II** de-coherence would take place in $CP_2$ degrees of freedom in a step-wise manner and correspond to the decay to MEs with a smaller covering group $G_b$ ($Z_{n_b}$ or or $Z_{n_b}$ plus reflection). The process leading to the eventual detection would be stepwise symmetry breaking.

Some words about the identification of the Planck constant are in order.

1. One could introduce separate Planck constants as units of $M^4$ and $CP_2$ quantum numbers since the symmetries in these degrees of freedom commute. Division of $CP_2$ by $G_b$ means that $CP_2$ Planck constant is multiplied by $n_b$. Same for $M^4$. Covering space of $CP_2$ means that $CP_2$ Planck constant is divided by $n_b$ (anyonization). Same for $M^4$.

2. The scaling of $M^4$ Planck constant by $\lambda$ induces a scaling of $M^4$ covariant metric by $\lambda^2$ so that both quantum lengths and space-time distances are scaled by $\lambda$. Same applies to $CP_2$.

3. The invariance of Kähler action under overall scaling of metric allows to regard the scaling of $M^4$ by $\lambda_a$ and $CP_2$ metric by $\lambda_b$ as scaling of of $M^4$ metric by $\lambda_a/\lambda_b$. This means that one can do with single Planck constant only given by the formulas above. By definition $CP_2$ Planck constant is scaled to $\hbar_0$.

### 5.2.3 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. 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, the necessarily spherical dark graviton emitted in the transition would carry away an essentially astrophysical energy.

The only resolution of the problem is that 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), and decays gradually to gravitons with smaller values of Planck constant. As a matter fact, the measurement process should induce this kind of decay. The prediction is that energy is emitted in bunches and this 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 type 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 and 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.

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.

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.

### 5.2.4 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.

**Option I**: Orbital plane defines the natural quantization axis of angular momentum. Spherical graviton corresponds to a graviton with very unit of angular momentum corresponding to $G_a$ invariance. Graviton has very large orbital angular momentum plus spin 2. One could quite well ask whether this kind of gravitons are physical.

**Option II**: Spherical graviton can be seen as a bundle of spherical gravitons corresponding to $n_b$ sheets of $CP_2$ covering having $n_a$ as angular momentum unit including spin. For $n_a = 1$ the ordinary gravitons associated with the giant graviton have same angular momentum so that the giant graviton can be regarded as Bose-Einstein condensate of ordinary gravitons. Orbital angular momentum is relatively small and can vanish for $n_a = 1$. Obviously **Option II** is intuitively more plausible than **Option I**).

The total angular momentum of the giant graviton 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.

If all elementary particles with gravitons included are maximally quantum critical systems, giant graviton should contain $r(G, S) = n_a/n_b$ ($n_a n_b$) ordinary gravitons for **Option I** and $r(G, S) = n_a n_b$ for **Option II**. For the latter the interpretation is clear. For **Option I** this number is not an integer for $n_b > 1$. A possible interpretation is that in this case gravitons possess fractional spin corresponding to the fact that rotation by $2\pi$ gives a different point in the $n_b$-fold covering of $M^4$ point by $CP_2$ points. In any case, this gives an estimate for the number of ordinary gravitons and 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.

#### 5.2.5 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 [D1].

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 [J4, K4] 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-decoherence 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 pointwise 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.

### 5.3 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 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?

### 5.3.1 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. Consider for simplicity Option b) with $n_a = 1$ which looks intuitively more plausible.

Now ME would correspond to $n_b$-"Riemann-sheeted" 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.

Obviously the classical behavior is essentially the same as predicted by general relativity at each "Riemann sheet". 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 $r$-fold.

### 5.3.2 Sequential de-coherence

Suppose that the detecting system has some mass $m$ and suppose that the gravitational interaction is mediated by the gravitational field body connecting the two systems.

The Planck constant must characterize the system formed by dark graviton and measuring system. In the case that $E$ is comparable to $m$ or larger, the expression for $r\hbar/\hbar_0$ must replaced with the relativistically invariant formula in which $m$ and $E$ are replaced with the energies in center of mass system. This gives

$$r = \frac{GmE}{v_0(1+\beta)\sqrt{1-\beta)}} \ , \ \beta = z(-1+\sqrt{1+\frac{2}{x}}) \ , \ x = \frac{E}{2m} \ . \quad (19)$$

Assuming $m >> E_0$ this gives in a good approximation $r = Gm_1E_0/v_0 = G^2m_1mM/v_0^2$. Note that in the interaction of identical masses ordinary $\hbar$ is possible for $m \leq \sqrt{v_0}M_{Pl}$. For $v_0 = 2^{-11}$ the critical mass corresponds roughly to the mass of water blob of radius 1 mm.

One can interpret the formula by saying that de-coherence splits from the incoming dark graviton dark piece having energy $E_1 = (Gm_1E_0/v_0)\omega$, which makes a fraction $E_1/E_0 = (Gm_1/v_0)\omega$ from the energy of the graviton. At the $n$:th step of the process the system would split from the dark graviton of previous step the fraction

$$\frac{E_n}{E_0} = (\frac{G\omega^n}{v_0})^n \prod_i (m_i) \ .$$

from the total emitted energy $E_0$. De-coherence process would proceed in steps such that the typical masses of the measuring system decrease gradually as the process goes downwards in length and time scale hierarchy. This splitting process should lead at large distances to the situation in which the original spherical dark graviton has split to ordinary gravitons with angular distribution being same as predicted by GRT.

The splitting process should stop when the condition $r \leq 1$ is satisfied and the topological light ray carrying gravitons becomes 1-sheeted covering of $M^4$. For $E << m$ this gives $GmE \leq v_0$ so that $m >> E$ implies $E << M_{Pl}$. For $E >> m$ this gives $GE^{3/2}m^{1/2} < 2v_0$ or

$$\frac{E}{m} \leq (\frac{2v_0}{Gm^2})^{2/3} \quad . \tag{20}$$

#### 5.3.3 Information theoretic aspects

The value of $r = \hbar/\hbar_0$ depends on the mass of the detecting system and the energy of graviton which in turn depends on the de-coherence history in corresponding manner. Therefore the total energy absorbed from the pulse codes via the value of $r$ information about the masses appearing in the de-coherence process. For a process involving only single step the value of the source mass can be deduced from this data. This could some day provide totally new means of deducing information about the masses of distant objects: something totally new from the point of view of classical and string theories of gravitational radiation. This kind of information theoretic bonus gives a further good reason to take the notion of quantized Planck constant seriously.

If one makes the stronger assumption that the values of $r$ correspond to ruler-and-compass rationals expressible as ratios of the number theoretically preferred values of integers expressible as $n = 2^k \prod_s F_s$, where $F_s$ correspond to different Fermat primes (only four is known), very strong constraints on the masses of the systems participating in the de-coherence sequence result. Analogous conditions appear also in the Bohr orbit model for the planetary masses and the resulting predictions were found to be true with few per cent. One cannot therefore exclude the fascinating possibility that the de-coherence process might in a very clever manner code information about masses of systems involved with its steps.

#### 5.3.4 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.

## 5.4 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.

### 5.4.1 Leakage of the giant graviton to sectors of imbedding space with smaller value of Planck constant

Consider first the model for the leakage of giant graviton to the sectors of $H$ with smaller Planck constant.

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). For **Option I** giving $\hbar/\hbar_0 = n_a/n_b$ the large discrete group would be $Z_{n_a}$ would act naturally as rotations around the direction of propagation for ME. For **Option II** giving $\hbar/\hbar_0 = n_a n_b$ the large discrete group would be $Z_{n_b}$ acting in $CP_2$ degrees of freedom.

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

$$\frac{S(ME)}{4\pi r^2}\hbar(G,S)\omega \quad = \quad \hbar(ME,G)\omega \ . \tag{21}$$

   or

$$\frac{S(ME)}{4\pi r^2} \quad = \quad \frac{\hbar(ME,G)}{\hbar(G,S)} \simeq \frac{E(ME)}{M(S)} \ . \tag{22}$$

   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.

### 5.4.2 The direct detection of giant graviton is not possible for long distances

Primary detection would correspond to a direct flow of energy from the giant graviton to detector. Assume that the source is modellable using large $\hbar$ variant of the Bohr orbit model for hydrogen atom. Denote by $r$ the rationals defining Planck constant as $\hbar = r\hbar_0$.

For G-S system one has

$$r(G,S) = \frac{GME}{v_0} = GMmv_0 \times \frac{k}{n^3} . \tag{23}$$

where $k$ is a numerical constant of order unity and $m$ refers to the mass of planet. For Hulse-Taylor binary $m \sim M$ holds true.

For D-G system one has

$$r(D,G) = \frac{GM(D)E}{v_0} = GM(D)mv_0 \times \frac{k}{n^3} . \tag{24}$$

The ratio of these rationals (in general) is of order $M(D)/M$.

Suppose first that the detector has a disk like shape. This gives for the total number $n(D)$ of ordinary gravitons going to the detector the estimate

$$\begin{aligned} n(D) &= (\frac{d}{r})^2 \times n_a(G,S) = (\frac{d}{r})^2 \times GMmv_0 \times n_b(G,S) \times \frac{k}{n^3} \quad \text{for } \textbf{Option I} ,\\ n(D) &= (\frac{d}{r})^2 \times n_b(G,S) = (\frac{d}{r})^2 \times GMmv_0 \times \frac{1}{n_a(G,S)} \times \frac{k}{n^3} \quad \text{for } \textbf{Option II} . \end{aligned} \tag{25}$$

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

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

$n(D)$ cannot be smaller than the number of ordinary gravitons estimated using the Planck constant associated with the detector: $n(D) \geq n_a(D,G) = r(D,G)n_b(D,G)$ for **Option I** and $n(D) \geq n_b(D,G) = r(D,G)/n_a(D,G)$ for **Option II**. This gives the condition

$$\begin{aligned} \frac{d}{r} &\geq \sqrt{\frac{M(D)}{M(S)}} \times \sqrt{X} \times (\frac{k}{xn^3})^{1/2} ,\\ X &= \frac{n_b(D,G)}{n_b(G,S)} \quad \text{for } \textbf{Option I} ,\\ X &= \frac{n_a(G,S)}{n_a(D,G)} \quad \text{for } \textbf{Option II} . \end{aligned} \tag{26}$$

Suppose for simplicity that $n_i(D,G)/n_i(G,S) = 1$ ($i = a$ or $b$ depending on option) and $M(D) = 10^3$ kg and $M(S) = 10^{30}$ kg and $r = 200$ MPc $\sim 10^9$ ly, which is a typical distance for binaries. For $x = 1, k = 1, n = 1$ this gives roughly $d \geq 10^{-4}$ ly $\sim 10^{11}$ m, which is roughly the size of solar system. From energy conservation condition the entire solar system would be the natural detector in this case. $n_b(G,S) >> n_b(D,G)$ would be required for **Option I** to improve the situation. For **Option II** $n_a(D,G) >> n_a(G,S)$ would be necessary. Therefore direct detection of giant graviton by human made detectors is excluded.

### 5.4.3 Secondary detection

The previous argument leaves only the secondary detection into consideration. Assume that ME results in the primary de-coherence of a giant graviton. Also longer de-coherence sequences are possible and one can deduce analogous conditions for these.

Energy conservation gives

$$\frac{S(D)}{S(ME)} \times r(ME,G) = r(D,ME) \ . \tag{27}$$

Using the expression for $S(ME)$ from Eq. 22, this gives an expression for $S(ME)$ for a given detector area:

$$S(ME) = \frac{r(ME,G)}{r(D,ME)} \times S(D) \simeq \frac{E(G)}{M(D)} \times S(D) \ . \tag{28}$$

From $S(ME) = \frac{E(ME)}{M(S)} 4\pi r^2$ one obtains

$$r = \sqrt{\frac{E(G)M(S)}{E(ME)M(D))}} \times \sqrt{S(D)} \tag{29}$$

for the distance at which ME is created. The distances of binaries studied in LIGO are of order $D = 10^{24}$ m. Using $E(G) \sim Mv_0^2$ and assuming $M = 10^{30}$ kg and $S(D) = 1$ m$^2$ (just for definiteness), one obtains $r \sim 10^{25}(kg/E(ME))$ m. If ME is generated at distance $r \sim D$ and if one has $S(ME) \sim 10^6\ m^2$ (from the size scale for LIGO) one obtains from the equation for $S(ME)$ the estimate $E(ME) \sim 10^{-25}$ kg $\sim 10^{-8}$ Joule.

### 5.4.4 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

$$\begin{aligned} E_n &= \frac{1}{n^2}E_1 \ , \\ E_1 &= (Z\alpha)^2\frac{m}{4} = (\frac{Ze^2}{4\pi\hbar})^2 \times \frac{m}{4} \rightarrow \frac{m}{4}v_0^2 \ . \end{aligned} \tag{30}$$

$E_1$ 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

$$r_0 = \frac{\hbar}{Z\alpha m} \rightarrow \frac{GM}{v_0^2} \ . \tag{31}$$

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 $n \rightarrow n-k$ transition and orbital rotation frequency $\omega_n$ are given by

$$\begin{aligned} \omega(n, n-k) &= \frac{v_0^3}{GM} \times (\frac{1}{n^2} - \frac{1}{(n-k)^2}) \simeq k\omega_n \ . \\ \omega_n &= \frac{v_0^3}{GMn^3} \ . \end{aligned} \tag{32}$$

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 $n \rightarrow n-k$ transition would be

$$E(n, n-k) = mv_0^2 \times (\frac{1}{n^2} - \frac{1}{(n-k)^2}) \ , \tag{33}$$

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.

## 5.5 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 naive guess would be $v_0 \sim 1$. 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 $\frac{Q^2g^2}{v_0} > 1$.

### 5.5.1 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 [F9] 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 [K6] essential in TGD based quantum model of metabolism and having also possible technological applications.

Various kinds of sharp pules [65] suggest themselves as a manner 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 [G3]). 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.

### 5.5.2 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 naivete 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).

# 6 New view about black-holes

In TGD framework the imbedding 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 [D3]. Black-hole would be replaced by a gigantic particle having no electro-weak interactions since the state would be created using super-canonical generators and generate its mass via p-adic thermodynamics. Scwartschild radius equals to Compton length if the generalization of Nottale formula for Planck constant holds true. Super-canonical 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.

## 6.1 Super-canonical 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-canonical algebra [B2, B3, B4], 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-canonical algebra is crucial for the construction of configuration space Kähler geometry. If one assumes that super-canonical 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-canonical bosons in TGD based model of hadron masses is discussed in [F4] and here only a brief summary is given.

As explained in [F4], 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-canonical gluons. Baryonic space-time sheet with $k = 107$ would contain a many-particle state of super-canonical 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.

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-canonical quanta. If the topological mixing for super-canonical bosons is equal to that for $U$ type quarks then a 3-particle state formed by 2 super-canonical 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-canonical 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-canonical bosons suggest a solution to several other anomalies related to hadron physics. The events observed for a couple of years ago in RHIC [31] 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-canonical 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 [30]. 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-canonical matter has no electro-weak interactions and is therefore dark matter in a strict sense. The exchange of super-canonical $J = 2$ 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-canonical 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-canonical degrees of freedom.

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

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

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

An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of $5\times10^{10}$ GeV are baryons, which have lost their valence quarks in a collision with hadron and therefore have no interactions with the microwave background so that they are able to propagate through long distances.

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

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

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) \ , \tag{34}$$

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

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

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2, \tag{35}$$

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

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

$$S = \frac{A}{4G} \times \hbar = \pi G M^2 \times \hbar \ . \tag{36}$$

   For the p-adic variant of the law Planck mass is replaced with $CP_2$ mass and $klog(2) \simeq log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if $k$ is prime and wormhole throats have $M^4$ radius given by p-adic length scale $L_k = \sqrt{k}R$ which is exponentially smaller than $L_p$. For macroscopic super-canonical black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [D3] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses $M$ and $m$ [D6] 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

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \ \ v_0 = 1/2 \ . \tag{37}$$

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 [D6]. Even without this constraint $M^2$ is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

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

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

7. In TGD light-like partonic 3-surfaces are the fundamental objects and space-time interior defines only the classical correlates of quantum physics.

The space-time sheet containing the highly entangled cosmic string might be separated from environment by a wormhole contact with size of black-hole horizon.

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

# 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 [32]. 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 passing 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 imbeddings 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 imbedding 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 imbedding 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 imbedding 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 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 imbedding 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 jerkwise 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 jerkwise expansion indeed seems to occur.

*5. Do cosmic strings with negative gravitational mass cause the phase tran-*

*sition 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 [36] 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. *Imbeddings of De Sitter space*

De Sitter space is possible as a vacuum extremal in TGD framework. There exists infinite number of imbeddings 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 imbedding to $M^4 \times X$ as a vacuum extremal. The imbedding 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 $\alpha$ 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 imbedding corresponds to the region $a^2 > -R^2$ containing future and past lightcones. 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 imbedding corresponding to future or past directed lightcone 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 ($\Lambda$ as characterizer of vacuum energy). If one includes to the gravitational momentum also metric tensor gravitational four-momentum density vanishes ($\Lambda$ 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 imbedding of De Sitter cosmology involves the choice of a preferred lightcone as does also quantization of Planck constant. Quantization of Planck constant involves the replacement of the lightcones 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 $\alpha$ and there is a covering of lightcone 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 [37] having similar imbedding to 5-D Minkowski space with two time like dimensions does not possess this kind of imbedding to $H$. Very probably no imbeddings exist so that TGD would allow only imbeddings of cosmologies with correct sign of $\Lambda$ 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 [38] 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 [51] 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 [52] 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 [60] 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 [55]. 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 [53] 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 [54] 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 [56] (orogeny), earth quake zones, and associated zones of volcanic activity [58].

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 [55], 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 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 [62] 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 [63], 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 [64] conforms with this picture.

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

Intra-terrestrial hypothesis [L5] 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 [59] 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 provide only the long sought mechanism of expansion and 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 About the anomalies of the cosmic microwave background

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

## 8.1 Background

Consider first some background.

1. The fluctuations of CMB reflect directly the fluctuations of energy density (acoustic waves) responsible for the formation of various structures: this follows from the proportionality $\rho \propto T^4$: one has $\Delta T/T \propto \Delta\rho/\rho \propto \Phi$, $\Phi$ is gravitational potential created by the density fluctuations. The spectrum

reflects the situation as thermal photons decoupled from matter and the matter became transparent to photons. The radiation comes from the sphere of last scattering $S^2$, which corresponds to the setting on of transparency and only Thomson scattering can affect the radiation after that time. For short angular distances the 2-point correlation functions at $S^2$ for the fluctuations are suppressed: this is due to a rapid increase of photon free path during the transition making possible exponential damping of the fluctuations of energy density for angular separation $\theta < 1$ degree at which the amplitude is maximum. Quite generally, at the maxima of correlation function the photons almost decouple from the acoustic fluctuations.

2. The analysis of fluctuation spectrum of CMB in general relativistic context requires a solution of Einstein's equations for small perturbations of Robertson Walker metric in presence of matter. It is convenient to decompose the perturbation of the metric Robertson-Walker coordinates using representations of rotation group [42]. The perturbation of $g_{tt}$ is scalar, the perturbation of $g_{ti}$ decomposes to a gradient of a scalar and rotor of a vector, and the perturbation of $g_{ij}$ corresponds to a scaling of the 3-metric represented by a scalar, double gradient of scalar, and genuinely tensorial part corresponding to classical gravitational radiation. From the four scalar modes two can be eliminated as mere coordinate changes without actual physical content. It is believed that only the scalar perturbations and tensor perturbation are significant. For the WMAP data only scalar perturbations matter.

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

4. The predictions of the inflationary scenario follow from the assumption that fluctuations correspond to primordial quantum fluctuations of inflaton field which expanded with an exponential rate to macroscopic fluctuations during the inflationary period. The spectrum of perturbations is assumed to be Gaussian and to obey approximate scale invariance [39]. Gaussianity holds true in 3-D momentum space and states that correlation function for the fluctuations of the energy density is proportional to 3-D delta function in momentum space. In other words, the Fourier components of the density perturbation are statistically independent. The coefficient of delta function can depend on the magnitude of 3-momentum.

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

## 8.2 Anomalies CMB

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

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

1. There is dipole term in the spectrum identifiable in terms of motion of the galaxy cluster containing Milky Way relative to the reference frame of the CMB. The cluster appears to be moving with velocity $627 \pm 22$ km/s in the direction of galactic longitude $(l = 264.4, b = 48.4)$ degrees [40].

2. Hemispherical power asymmetry [44] means that the amplitude of the fluctuations is not same at the opposite sides of the galactic plane (rather near to ecliptic plane): the difference in the amplitude is about 10 per cent. This does not mean that the mean value of temperature would differ at the opposite sides. The anomaly can be parameterized by a deviation of the amplitude from constant by an additive dipole term of amplitude .114 and in the direction (l,b)= (225,-27) degrees in galactic coordinates. Freeman suggest that the asymmetry can be eliminated for $l \leq 8$ by a slight modification of the CMB dipole [43]. In the average sense this might hold true since dipole term has odd parity. The temperature fluctuations are also stronger in southern than northern galactic hemisphere and there is a peculiar cold spot at southern hemisphere. Dipole term cannot eliminate this kind of anomalies. One might hope that the elimination of the galactic foreground - when done properly - might eliminate this asymmetry. The subtraction of the contribution from the galactic plane affects in the first approximation only the even harmonics: this would affect the interference pattern between even and odd harmonics.

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

i) One can assign to the $l$:th contribution a unique axis maximizing angular momentum dispersion and these directions turn out to be very near to each other for $l = 2$ and $l = 3$ contributions [47]. De Oliveiro Costa *et al* noticed that this anomaly could be understood if the Universe has a compact direction in this direction of size of order horizon radius. This explanation is ruled out by other tests, including the absence of matched circles. The modification of the contribution from galactic plane would affect the direction assignable to $l = 2$ harmonic but would not affect considerably $l = 3$ contribution. Hence this effect might be due a wrong subtraction.

ii) The contribution from the harmonics with angular momentum $l$ can be characterized in terms of $l$ unit vectors: what one does is essentially expression of the contribution as a product of the direction cosines between radial unit vector and $l$ unit vectors [45]. $l = 2$ harmonics defined two vectors of this kind and their cross product defines what is called an area vector. For $l = 3$ there are three vectors of this kind and one can define three area vectors. It turns out that the planes defined by $l = 2$ area vector and two $l = 3$ area vectors are very near to each other and nearly orthogonal to the plane of ecliptic (and thus also galactic plane). These vectors are in reasonable approximation in galactic plane and aligned with the direction of CMB dipole whereas the direction. The direction of the third $l = 3$ area vector deviates about 10 degrees from the normal of the galactic plane.

Again the smallness of $l = 2$ contribution raises the question whether the dipole correction and galactic foreground subtraction are done properly. Freeman and collaborators [43] have proposed that a proper subtraction of CMB dipole might allow to get rid of this anomaly. According to [46] this is probably not possible. In the case of $l = 3$ harmonics galactic subtraction affecting only even harmonics should not have any appreciable effect. The presence of cold spot near Galactic center and hot spot near Gum Nebula, both in the galactic plane, could also relate to the fact that the area vector is aligned with galactic plane.

Consider next two-point correlation functions.

1. The function $C(\theta)$ is obtained by averaging the fluctuations for all pairs of points at the sphere of last scattering separated by angle $\theta$. $C(\theta)$ with galactic cutoff vanishes for $\theta > 60$ degrees the correlation function vanishes in good approximation [46]. There is also a strange finding[50] suggesting a strong correlation between the fluctuation spectrum and 2-point correlation function. Large scale cutoff of $C(\theta)$ in the full-sky maps without galactic cutoff is absent while cut-sky maps with the galactic contribution masked are anomalous. The galactic cut is also almost equivalent with the masking of the cold and hot spot assignable to the galactic plane. Accepting the hot and cold spots in the galactic plane as real would give large scale correlations of 2-point correlation functions and vice versa. Also the

subtraction of the anomalous quadrupole and octopole contributions from the 1-point correlation function brings back the large scale power. It is also essential that the multipole vectors of these contributions are nearly parallel. Hence it seems that one can choose between two evils: either the power cutoff at large scales or the axis of evil.

2. For low $l$ harmonics statistical isotropy assumption fails [46]. This means that the correlation functions $\langle a_{lm}a_{l_1,-m_1}\rangle$ in the expansion of $\Delta T$ in terms of spherical harmonics $Y_{l,m}$ taken over temporal ensemble are not of form $C_l\delta_{l,l_1}\delta_{m,m_1}$, where $C_l$ would define coefficients of $C(\theta)$ in terms of $P_l(\theta)$. Quadrupole terms ($l=2$) are also anomalously small.

There are also other anomalous correlations.

1. Unexpectedly high correlation between temperature and E-mode polarization caused by Thomson scattering of CMB photons can be seen as an evidence for a large optical depth and very early star formation [49].

2. Gaussianity predicts that three-point correlation functions for density fluctuations vanish. Hence also three-point correlation functions at the sphere of the last scattering should vanish. There is some evidence that this is not the case [48]: the proposed deviation from Gaussianity is parameterized by writing the perturbation of the gravitational potential in the form $\Phi = \Phi_L + f_{NL}(\Phi_L^2 - \langle\Phi_L^2\rangle)$.

## 8.3 What TGD could say about the anomalies?

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

### 8.3.1 Implications of p-adic and dark matter hierarchies

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

1. In TGD framework there are two hierarchies: hierarchy of p-adic space-time sheets and hierarchy of Planck constants. p-Adic length scales are

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

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

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

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

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

2. The value of the integer $k$ characterizing p-adic length scale at the time of the transition can be estimated from the radius for the sphere of last scattering identified as radius $R = a(t)$. The transition to matter dominated Universe began in about 400, 000 years old universe. Coupling took about 120,000 years and was finished at the age of 500,000 years. From this one can estimate the p-adic length scale in question as light-cone proper time $a(t)/a_0 = (t/t_0)^{2/3}$ in matter dominated cosmology identifiable as curvature radius $R$ in GRT based RW cosmology. My own estimate $a = 3 \times 10^7$ ly in [D5] gives $k \sim 355$.

3. Identifying $\Delta\rho_i$ for a given particle as the energy density $\rho_{i,d}$ of dark variant of the particle implies adiabaticity if one has $\rho_{i,d}/\rho_i = constant$. This is achieved by assuming that the energy densities scale like $\rho_{tot}$, that is one has $\rho_{d,i} = (\hbar/\hbar_0)^{-n}\rho_i \propto (\hbar/\hbar_0)^{-n}\ a^{-n}$. $n = 2$ is suggested by the early critical cosmology discussed [D5]. This would give $\Delta\rho_i/\rho_i = (\hbar_0/\hbar)^2$. From $\Delta T/T \simeq 10^{-5}$ one would have $r = \hbar/\hbar_0 \sim 300$. The estimate for $r$ is not too far from $k \sim 355$, which might mean that $r = k$ holds true implying that the $r$ would increase logarithmically with the p-adic length scale of the space-time sheet.

Consider next the anomalies from phenomenological point of view.

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

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

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

2. As already noticed, the presence of galactic cold and hot spots and axis of evil seem to be the price to be paid for the presence of large scale power [50]. The finite size of the space-time sheets forcing the vanishing of 2-point correlation function for large angular separations could thus conform

with the non-CMB explanation of galactic cold and hot spots and allow to get rid of axis of evil. The pair of cold and hot spots indeed gives a large negative contribution to $C(\theta)$. The finite size of space-time sheets could also explain the hemispherical asymmetry and why fluctuations are stronger at the southern galactic hemisphere.

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

A couple of warnings are in order.

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

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

### 8.3.2 Perturbations of the critical cosmology: the naive approach

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

1. Concerning the perturbations of the critical cosmology, a natural condition would be that only vacuum extremals of Kähler action are allowed. This means that only perturbations giving rise to 4-surfaces belonging to $M^4 \times Y^2 \subset M^4 \times CP_2$, $Y^2$ Lagrangian sub-manifold of $CP_2$, are allowed. If all small deformations of the critical cosmology are allowed, curvature scalar cannot vanish in general. In this framework the notion of adiabaticity involving statements about various particles does not have any

obvious meaning whereas the notion of iso-curvature fluctuations can be formulated. The vanishing of the curvature scalar makes sense for the perturbations of RW metric representing vacuum extremals but would break the symplectic symmetry in $CP_2$ degrees of freedom. Note also that many-sheeted space-time and the generalization of imbedding space induced by hierarchy of Planck constants are quite essential piece of TGD vision and are not taken into account in this naive approach.

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

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

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

I have already earlier [D5] proposed that CMB spectrum might be understood in terms of conformal field theory. If some variant of conformal field theory works, the general prediction is the breaking of conformal invariance meaning the appearance of the counterpart of the spectral index from the breaking of conformal symmetry by the generation of central extension to super-conformal algebra. In this framework $1-n_s$ corresponds to an anomalous dimension having a discrete spectrum in conformal theories and known once the representation of Super Virasoro algebra is known. It would not be surprising if $n_s$ would depend on the value of $\hbar$, which defines a quantum phase $q$ playing also a key role in conformal field theories. Second important prediction would be that 3-point correlation functions are predictable and non-vanishing unless the conformal field theory in question is not free. This would allow the possibility of non-Gaussian behavior.

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

1. One must consider small perturbations of the critical cosmology which are also vacuum extremals. This means that the perturbations correspond to surface $X^4 \subset M^4 \times Y^2$, where $Y^2$ corresponds to Lagrangian sub-manifold of $CP_2$ having vanishing induced Kähler form. If one poses no other conditions the vacuum extremals possess symplectic transformations of $CP_2$ leaving given $Y^2$ invariant as symmetries. These transformations relate closely to so called super-canonical symmetries which are basic super-conformal symmetries of quantum TGD besides Kac-Moody type symmetries assignable to light-like 3-surfaces identified as basic dynamical objects. Also symplectic (or rather contact-) transformations of $r_M = constant$ sphere of light-cone boundary act as this kind of symmetries which raises the question whether the analog of conformal field theory based having the symplectic group of light-cone boundary as symmetries might be a proper manner to characterize the vacuum degeneracy in quantum TGD.

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

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

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

#### 8.3.4 Could a symplectic analog of conformal field theory work?

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

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

2. For a symplectic scalar field $n \geq 3$-point functions with a vanishing anomalous dimension would be functions of the symplectic invariants defined by the areas of geodesic polygons defined by subsets of the arguments as

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

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

$$\Phi_k(s_1)\Phi_l(s_2) = \int c_{kl}^m f(A(s_1, s_2, s_3))\Phi_m(s)d\mu_s \quad . \tag{38}$$

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

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

$$\langle\Phi_k(s_1)\Phi_l(s_2)\rangle = \int c_{kl}f(A(s_1, s_2, s))d\mu_s \quad . \tag{39}$$

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

CMB data suggest breaking of rotational and reflection symmetries. A possible mechanism of spontaneous symmetry breaking is based on the observation that in TGD framework the hierarchy of Planck constants assigns to each sector of the generalized imbedding space a preferred quantization axes. The selection of the quantization axis is coded also to the geometry of "world of classical worlds", and to the quantum fluctuations of the metric in particular.

Clearly, symplectic QFT with spontaneous symmetry breaking would provide the sought-for really deep reason for the quantization of Planck constant in the proposed manner.

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

$$\Delta A(s_1, s_2, s_3) \equiv A(s_1, s_2, s_3, N) - A(s_1, s_2, s_3, S) \tag{40}$$

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

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

$$\begin{aligned} \langle (\Phi_k(s_1)\Phi_l(s_2))\Phi_m(s_3)\rangle &= c^r_{kl}\int f(\Delta A(s_1,s_2,s))\langle \Phi_r(s)\Phi_m(s_3)\rangle d\mu_s \\ &= \qquad (41) \end{aligned}$$

$$c^r_{kl}c_{rm}\int f(\Delta A(s_1,s_2,s))f(\Delta A(s,s_3,t))d\mu_s d\mu_t \ . \tag{42}$$

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

3. 2-point correlation function would be given by

$$\langle \Phi_k(s_1)\Phi_l(s_2)\rangle = c_{kl}\int f(\Delta A(s_1,s_2,s))d\mu_s \tag{43}$$

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

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

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

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

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

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

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

1. It is natural to introduce the moduli space for n-tuples of points of the symplectic manifold as the space of symplectic equivalence classes of n-tuples. In the case of sphere $S^2$ convex n-polygon allows $n+1$ 3-sub-polygons and the areas of these provide symplectically invariant coordinates for the moduli space of symplectic equivalence classes of n-polygons ($2^n$-D space of polygons is reduced to $n+1$-D space). For non-convex polygons the number of 3-sub-polygons is reduced so that they seem to correspond to lower-dimensional sub-space. In the case of $CP_2$ n-polygon allows besides the areas of 3-polygons also 4-volumes of 5-polygons as fundamental symplectic invariants. The number of independent 5-polygons for n-polygon can be obtained by using induction: once the numbers $N(k,n)$ of independent $k \leq n$-simplices are known for n-simplex, the numbers of

$k \leq n+1$-simplices for $n+1$-polygon are obtained by adding one vertex so that by little visual gymnastics the numbers $N(k, n+1)$ are given by $N(k, n+1) = N(k-1, n) + N(k, n)$. In the case of $CP_2$ the allowance of 3 analogs $\{N, S, T\}$ of North and South poles of $S^2$ means that besides the areas of polygons $(s_1, s_2, s_3)$, $(s_1, s_2, s_3, X)$, $(s_1, s_2, s_3, X, Y)$, and $(s_1, s_2, s_3, N, S, T)$ also the 4-volumes of 5-polygons $(s_1, s_2, s_3, X, Y)$, and of 6-polygon $(s_1, s_2, s_3, N, S, T)$, $X, Y \in \{N, S, T\}$ can appear as additional arguments in the definition of 3-point function.

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

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

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

4. This picture based on elementary geometry might make sense also in the

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

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

#### 8.3.5 What symplectic QFT tells about fluctuations?

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

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

Consider first 2-point correlation functions.

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

$$\begin{aligned} C(\theta) &= \langle \Phi(s_1)\Phi(s_2)\rangle = \sum_n f_n \langle \int [\Delta A(s_1,s_2,s)]^n d\mu_s\rangle \ , \\ \Delta A(s_1,s_2,s) &= A(s_1,s_2,s,N) - A(s_1,s_2,s,P) \ . \end{aligned} \tag{44}$$

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

$$C(\theta) = \sum_n f_{2n} \langle \int [\Delta A(s_1,s_2,s)]^{2n} d\mu_s\rangle \ . \tag{45}$$

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

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

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

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

Consider next the fluctuations.

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

2. The intuitive notions about distribution for the fluctuations and amplitude of fluctuations are not readily expressible in terms of n-point correlation functions since the moments $\langle \Phi(s)^k \rangle$ vanish identically. One can however perform smoothing out of these quantities and replace the quantity $\langle \Phi(s)^k \rangle$ with $\int \langle \prod_i \Phi(s_i) \rangle \prod_k d\mu_{s_k}/A^n$, where the integrations are over a small disk of area $A$ around point $s$. This gives a well defined variance and one can speak about fluctuation amplitude in a given resolution defined by $A$. The moments define in a given resolution what the probability distribution for the fluctuations means.

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

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

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

The idea about hierarchy of Planck constants was inspired by the finding that the orbits of inner and outer planets could be regarded in a reasonable approximation as Bohr orbits but with Planck constant which was gigantic and was for outer planets smaller than for inner planets by a factor of 1/5 [D6]. The gigantic value of the Planck constant at the flux tubes mediating gravitational interactions implies quantum coherence in cosmic scales and this could allow a radically new interpretation of CMB anomalies. In particular, it could explain why the preferred equatorial plane of the sphere of last scattering predicted by symplectic QFT with spontaneous symmetry breaking is near to the galactic plane.

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

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

the quantum fluctuation spectrum (say the direction of the quantization axis defining equatorial asymmetry)?

3. Could one imagine that "we" as observers are entangled with the possible states of the galactic gravito-magnetic body in turn entangled gravitationally with the quantum fluctuations at the sphere of last scattering and that the measurement of the state of galactic system telling the direction of galactic plane, etc... selects also the dark quantum fluctuation in the geometric past. If so, the selection of quantization axes for fluctuations would be same for the observer and sphere of last scattering. If the choice is dictated by the observer, the breaking of rotational symmetry and parity symmetry and choice of galactic plane as preferred plane would be induced by quantum measurement. Note that this does not lead to any obvious contradictions since the spheres of last scattering are in principle different for observers at different positions of the Universe. If this interpretation is correct, the strange anomalies of CMB would provide a rather dramatic verification for the Wheeler's idea about participatory Universe.

# 9 Appendix

In this appendix the generalization of the notion of imbedding space realizing mathematically the hierarchy of Planck constants is discussed. Also orbital radii of exo-planets as test of the theory are considered.

## 9.1 Generalization of the notion of imbedding space

Quite generally, the hierarchy of Planck constant is realized by generalizing the notion of imbedding space such that one has a book like structure with various almost-copies of imbedding 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 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. At classical level the interactions correspond to the leakage of magnetic and electric fluxes and radiation fields between different pages of the book.

The original generalization of imbedding space was too restricted and the belief that the proposed generalization of the imbedding space could explain naturally phenomena like quantum Hall effect involving fractionization of quantum numbers like spin and charge turned out to be wrong. The idea was that a given page of the book like structure would correspond to an orbifold obtained from $H$ by identifying the points of $H$ obtained from each other by the action of group $G_a \times G_b$, where the factors act in $M^4$ and $CP_2$ degrees of freedom. As a matter fact, this identification implies just the opposite of fractionization if these quantum numbers are assigned with the symmetries of the imbedding space. For instance, quantization unit for orbital angular momentum becomes $n_a$ where $Z_{n_a}$ is the maximal cyclic subgroup of $G_a$.

One can however imagine of obtaining fractionization at the level of imbedding space for space-time sheets, which are analogous to multi-sheeted Riemann surfaces (say Riemann surfaces associated with $z^{1/n}$ since the rotation by $2\pi$ understood as a homotopy of $M^4$ lifted to the space-time sheet is a non-closed curve. Continuity requirement indeed allows fractionization of the orbital quantum numbers and color in this kind of situation.

### 9.1.1 Both covering spaces and factor spaces are possible

The observation above stimulates the question whether it might be possible in some sense to replace $H$ or its factors by their multiple coverings.

1. This is certainly not possible for $M^4$, $CP_2$, or $H$ since their fundamental groups are trivial. On the other hand, the fixing of quantization axes implies a selection of the sub-space $H_4 = M^2 \times S^2 \subset M^4 \times CP_2$, where $S^2$ is a geodesic sphere of $CP_2$. $\hat{M}^4 = M^4 \backslash M^2$ and $\hat{CP}_2 = CP_2 \backslash S^2$ have fundamental group $Z$ since the codimension of the excluded sub-manifold is equal to two and homotopically the situation is like that for a punctured plane. The exclusion of these sub-manifolds defined by the choice of quantization axes could naturally give rise to the desired situation.

2. $H_4$ represents a straight cosmic string. Quantum field theory phase corresponds to Jones inclusions with Jones index $\mathcal{M} : \mathcal{N} < 4$. Stringy phase would by previous arguments correspond to $\mathcal{M} : \mathcal{N} = 4$. Also these Jones inclusions are labelled by finite subgroups of $SO(3)$ and thus by $Z_n$ identified as a maximal Abelian subgroup.

   One can argue that cosmic strings are not allowed in QFT phase. This would encourage the replacement $\hat{M}^4 \times \hat{CP}_2$ implying that surfaces in $M^4 \times S^2$ and $M^2 \times CP_2$ are not allowed. In particular, cosmic strings and $CP_2$ type extremals with $M^4$ projection in $M^2$ and thus light-like geodesic without zitterwebegung essential for massivation are forbidden. This brings in mind instability of Higgs=0 phase.

3. The covering spaces in question would correspond to the Cartesian products $\hat{M}^4{}_{n_a} \times \hat{CP}_{2n_b}$ of the covering spaces of $\hat{M}^4$ and $\hat{CP}_2$ by $Z_{n_a}$ and $Z_{n_b}$ with fundamental group is $Z_{n_a} \times Z_{n_b}$. One can also consider extension by replacing $M^2$ and $S^2$ with its orbit under $G_a$ (say tedrahedral, octahedral, or icosahedral group). The resulting space will be denoted by $\hat{M}^4 \hat{\times} G_a$ *resp.* $\hat{CP}_2 \hat{\times} G_b$.

4. One expects the discrete subgroups of $SU(2)$ emerge naturally in this framework if one allows the action of these groups on the singular sub-manifolds $M^2$ or $S^2$. This would replace the singular manifold with a set of its rotated copies in the case that the subgroups have genuinely

3-dimensional action (the subgroups which corresponds to exceptional groups in the ADE correspondence). For instance, in the case of $M^2$ the quantization axes for angular momentum would be replaced by the set of quantization axes going through the vertices of tedrahedron, octahedron, or icosahedron. This would bring non-commutative homotopy groups into the picture in a natural manner.

5. Also the orbifolds $\hat{M}^4/G_a \times \hat{CP_2}/G_b$ can be allowed as also the spaces $\hat{M}^4/G_a \times (\hat{CP_2} \hat{\times} G_b)$ and $(\hat{M}^4 \hat{\times} G_a) \times \hat{CP_2}/G_b$. Hence the previous framework would generalize considerably by the allowance of both coset spaces and covering spaces.

There are several non-trivial questions related to the details of the gluing procedure and phase transition as motion of partonic 2-surface from one sector of the imbedding space to another one.

1. How the gluing of copies of imbedding space at $M^2 \times CP_2$ takes place? It would seem that the covariant metric of $M^4$ factor proportional to $\hbar^2$ must be discontinuous at the singular manifold since only in this manner the idea about different scaling factor of $M^4$ metric can make sense. This is consistent with the identical vanishing of Chern-Simons action in $M^2 \times S^2$.

2. One might worry whether the phase transition changing Planck constant means an instantaneous change of the size of partonic 2-surface in $M^4$ degrees of freedom. This is not the case. Light-likeness in $M^2 \times S^2$ makes sense only for surfaces $X^1 \times D^2 \subset M^2 \times S^2$, where $X^1$ is light-like geodesic. The requirement that the partonic 2-surface $X^2$ moving from one sector of $H$ to another one is light-like at $M^2 \times S^2$ irrespective of the value of Planck constant requires that $X^2$ has single point of $M^2$ as $M^2$ projection. Hence no sudden change of the size $X^2$ occurs.

3. A natural question is whether the phase transition changing the value of Planck constant can occur purely classically or whether it is analogous to quantum tunnelling. Classical non-vacuum extremals of Chern-Simons action have two-dimensional $CP_2$ projection to homologically non-trivial geodesic sphere $S^2_I$. The deformation of the entire $S^2_I$ to homologically trivial geodesic sphere $S^2_{II}$ is not possible so that only combinations of partonic 2-surfaces with vanishing total homology charge (Kähler magnetic charge) can in principle move from sector to another one, and this process involves fusion of these 2-surfaces such that $CP_2$ projection becomes single homologically trivial 2-surface. A piece of a non-trivial geodesic sphere $S^2_I$ of $CP_2$ can be deformed to that of $S^2_{II}$ using 2-dimensional homotopy flattening the piece of $S^2$ to curve. If this homotopy cannot be chosen to be light-like, the phase transitions changing Planck constant take place only via quantum tunnelling. Obviously the notions of light-like homotopies (cobordisms) and classical light-like homotopies (cobordisms) are very relevant for the understanding of phase transitions changing Planck constant.

### 9.1.2 Do factor spaces and coverings correspond to the two kinds of Jones inclusions?

What could be the interpretation of these two kinds of spaces?

1. Jones inclusions appear in two varieties corresponding to $\mathcal{M}:\mathcal{N}<4$ and $\mathcal{M}:\mathcal{N}=4$ and one can assign a hierarchy of subgroups of $SU(2)$ with both of them. In particular, their maximal Abelian subgroups $Z_n$ label these inclusions. The interpretation of $Z_n$ as invariance group is natural for $\mathcal{M}:\mathcal{N}<4$ and it naturally corresponds to the coset spaces. For $\mathcal{M}:\mathcal{N}=4$ the interpretation of $Z_n$ has remained open. Obviously the interpretation of $Z_n$ as the homology group defining covering would be natural.

2. $\mathcal{M}:\mathcal{N}=4$ should correspond to the allowance of cosmic strings and other analogous objects. Does the introduction of the covering spaces bring in cosmic strings in some controlled manner? Formally the subgroup of $SU(2)$ defining the inclusion is $SU(2)$ would mean that states are $SU(2)$ singlets which is something non-physical. For covering spaces one would however obtain the degrees of freedom associated with the discrete fiber and the degrees of freedom in question would not disappear completely and would be characterized by the discrete subgroup of $SU(2)$.

   For anyons the non-trivial homotopy of plane brings in non-trivial connection with a flat curvature and the non-trivial dynamics of topological QFTs. Also now one might expect similar non-trivial contribution to appear in the spinor connection of $\hat{M}^2\hat{\times}G_a$ and $\hat{CP}_2\hat{\times}G_b$. In conformal field theory models non-trivial monodromy would correspond to the presence of punctures in plane.

3. For factor spaces the unit for quantum numbers like orbital angular momentum is multiplied by $n_a$ *resp.* $n_b$ and for coverings it is divided by this number. These two kind of spaces are in a well defined sense obtained by multiplying and dividing the factors of $\hat{H}$ by $G_a$ *resp.* $G_b$ and multiplication and division are expected to relate to Jones inclusions with $\mathcal{M}:\mathcal{N}<4$ and $\mathcal{M}:\mathcal{N}=4$, which both are labelled by a subset of discrete subgroups of SU(2).

4. The discrete subgroups of $SU(2)$ with fixed quantization axes possess a well defined multiplication with product defined as the group generated by forming all possible products of group elements as elements of $SU(2)$. This product is commutative and all elements are idempotent and thus analogous to projectors. Trivial group $G_1$, two-element group $G_2$ consisting of reflection and identity, the cyclic groups $Z_p$, $p$ prime, and tedrahedral, octahedral, and icosahedral groups are the generators of this algebra.

   By commutativity one can regard this algebra as an 11-dimensional module having natural numbers as coefficients ("rig"). The trivial group $G_1$, two-element group $G_2$¡ generated by reflection, and tedrahedral, octahedral, and icosahedral groups define 5 generating elements for this algebra. The products of groups other than trivial group define 10 units for this algebra so that there are 11 units altogether. The groups $Z_p$ generate a structure analogous to natural numbers acting as analog of coefficients of this structure. Clearly, one has effectively 11-dimensional commutative algebra in 1-1 correspondence with the 11-dimensional "half-lattice" $N^{11}$ ($N$ denotes natural numbers). Leaving away reflections, one obtains $N^7$. The projector representation suggests a connection with Jones inclusions. An interesting question concerns the possible Jones inclusions assignable to the subgroups containing infinitely manner elements. Reader has of course already asked whether dimensions 11, 7 and their difference 4 might relate somehow to the mathematical structures of M-theory with 7 compactified dimensions. One could introduce generalized configuration space spinor fields in the configuration space labelled by sectors of $H$ with given quantization axes. By introducing Fourier transform in $N^{11}$ one would formally obtain an infinite-component field in 11-D space.

5. How do the Planck constants associated with factors and coverings relate? One might argue that Planck constant defines a homomorphism respecting the multiplication and division (when possible) by $G_i$. If so, then Planck constant in units of $\hbar_0$ would be equal to $n_a/n_b$ for $\hat{H}/G_a \times G_b$ option and $n_b/n_a$ for $\hat{H}\hat{\times}(G_a \times G_b)$ with obvious formulas for hybrid cases. This option would put $M^4$ and $CP_2$ in a very symmetric role and allow much more flexibility in the identification of symmetries associated with large Planck constant phases.

### 9.1.3 Phase transitions changing the value of Planck constant

There are two basic kinds of phase transitions changing the value of Planck constant inducing a leakage between sectors of imbedding space. There are three cases to consider corresponding to

1. leakage in $M^4$ degrees of freedom changing $G_a$: the critical manifold is $R_+ \times CP_2$;

2. leakage in $CP_2$ degrees of freedom changing $G_b$: the critical manifold is $\delta M^4_+ \times S^2_{II}$;

3. leakage in both degrees of freedom changing both $G_a$ and $G_b$: the critical manifold is $R_+ \times S^2_{II}$. This is the non-generic case

For transitions of type 2) and 3) $X^2$ must go through vacuum extremal in the classical picture about transition.

Covering space can also change to a factor space in both degrees of freedom or vice versa and in this case $G$ can remain unchanged as a group although its interpretation changes.

The phase transitions satisfy also strong group theoretical constraints. For the transition $G_1 \rightarrow G_2$ either $G_1 \subset G_2$ or $G_2 \subset G_1$ must hold true. For maximal cyclic subgroups $Z_n$ associated with quantization axes this means that $n_1$ must divide $n_2$ or vice versa. Hence a nice number theoretic view about transitions emerges.

One can classify the points of critical manifold according to the degree of criticality. Obviously the maximally critical points corresponds to fixed points of $G_i$ that its points $z = 0, \infty$ of the spheres $S^2_r$ and $S^2_{II}$. In the case of $\delta M^4_+$ the points $z = 0$ and $\infty$ correspond to the light-like rays $R_+$ in opposite directions. This ray would define the quantization direction of angular momentum. Quantum phase transitions changing the value of $M^4$ Planck constant could occur anywhere along this ray (partonic 2-surface would have 1-D projection along this ray). At the level of cosmology this would bring in a preferred direction. Light-cone dip, the counterpart of big bang, is the maximally quantum critical point since it remains invariant under entire group $SO(3,1)$.

Interesting questions relate to the groups generated by finite discrete subgroups of $SO(3)$. As noticed the groups generated as products of groups leaving $R_+$ invariant and three genuinely 3-D groups are infinite discrete subgroups of SO(3) and could also define Jones inclusions. In this case orbifold is replaced with orbifold containing infinite number of rotated versions of $R_+$. These phases could be important in elementary particle length scales or in early cosmology.

As already explained, the original too restricted view about generalization of imbedding space led to the idea about p-adic fractal hierarchy of Josephson junctions. Although this vision can criticized as unrealistic I decided to keep the original section discussing this idea in detail.

Fractal hierarchy of Josephson junctions is not new in TGD framework. The development of quantitative models based on this notion has been however plagued by the absence of concrete idea about what these Josephson junctions look like. The dark matter hierarchy based on hierarchy of scaled up values of Planck constant when combined with the p-adic length scale hierarchy might allow to circumvent the problem.

An essential boost for the development of ideas have been the effects of ELF em fields in living matter explainable in terms of quantum cyclotron transitions in Earth's magnetic field. Especially the fact that these effects appear only in narrow temperature and amplitude windows has provided the key hints concerning the model for the hierarchy of Josephson junctions and EEGs. The discussion of these effects is left to a separate section.

## 9.2 Orbital radii of exoplanets as a test for the theory

Orbital radii of exoplanets serve as a test for the theory. Hundreds of them are already known and in [28] tables listing basic data for for 136 exoplanets can be found. Tables provide also references and links to sources giving data about stars, in particular star mass $M$ using solar mass $M_S$ as a unit. Hence one can test the formula for the orbital radii given by the expression

$$\frac{r}{r_E} = \frac{n^2}{5^2}\frac{M}{M_S}X \ ,$$
$$X = (\frac{n_1}{n_2})^2 \ ,$$
$$n_i = 2^{k_i}\times\prod_{s_i} F_{s_i} \ , \ F_{s_i}\in\{3,5,17,257,2^{16}+1\} \ . \quad (46)$$

Here a given Fermat prime $F_{s_i}$ can appear only once.

It turns out that the simplest option assuming $X = 1$ fails badly for some planets: the resulting deviations of order 20 per cent typically but in the worst cases the predicted radius is by factor of $\sim .5$ too small. The values of $X$ used in the fit correspond to $X \in \{(2/3)^2, (3/4)^2, (4/5)^2, (5/6)^2, (15/17)^2$ $, (15/16)^2, (16/17)^2\} \simeq \{.44, .56, .64, .69, .78, .88, .89\}$ and their inverses. The tables summarizing the resulting fit using both $X = 1$ and value giving optimal fit are given below. The deviations are typically few per cent and one must also take into account the fact that the masses of stars are deduced theoretically using the spectral data from star models. I am not able to form an opinion about the real error bars related to the masses.

In the tables $R$ denotes the value of minor semiaxis of the planetary orbit using AU as a unit and $M$ the mass of star using solar mass $M_S$ as a unit. $n$ is the value of the principal quantum number and $R_1$ the radius assuming $X = (r/s)^2 = 1$ and $R_2$ the value for the best choice of $X$ as ratio of "ruler and compass integers". The data about radii of planets are from tables at http://exoplanets.org/almanacframe.html and star masses from the references contained by the tables.

| Star Name | R | M | n | R1 | R1/R | r | s | R2/R |
|---|---|---|---|---|---|---|---|---|
| HD73256 | 0.037 | 1.05 | 1 | 0.042 | 1.14 | 16 | 15 | 1.00 |
| HD83443 | 0.040 | 0.79 | 1 | 0.032 | 0.79 | 15 | 17 | 1.01 |
| HD46375 | 0.040 | 1.00 | 1 | 0.040 | 1.00 | 1 | 1 | 1.00 |
| HD179949 | 0.040 | 1.24 | 1 | 0.050 | 1.24 | 17 | 15 | 0.97 |
| HD187123b | 0.040 | 1.06 | 1 | 0.042 | 1.06 | 1 | 1 | 1.06 |
| HD120136 | 0.050 | 1.30 | 1 | 0.052 | 1.04 | 1 | 1 | 1.04 |
| HD330075 | 0.046 | 0.70 | 1 | 0.028 | 0.61 | 4 | 5 | 0.95 |
| BD-103166 | 0.050 | 1.10 | 1 | 0.044 | 0.88 | 15 | 16 | 1 |
| HD209458 | 0.050 | 1.05 | 1 | 0.042 | 0.84 | 16 | 17 | 0.95 |
| HD76700 | 0.050 | 1.00 | 1 | 0.040 | 0.8 | 15 | 17 | 1.03 |
| HD217014 | 0.050 | 1.06 | 1 | 0.042 | 0.85 | 15 | 16 | 0.96 |
| HD9826b | 0.059 | 1.30 | 1 | 0.052 | 0.88 | 15 | 16 | 1.00 |
| HD49674 | 0.060 | 1.00 | 1 | 0.040 | 0.67 | 5 | 6 | 0.96 |
| HD68988 | 0.070 | 1.20 | 1 | 0.048 | 0.69 | 5 | 6 | 0.99 |
| HD168746 | 0.065 | 0.88 | 1 | 0.035 | 0.54 | 3 | 4 | 0.96 |
| HD217107 | 0.070 | 0.98 | 1 | 0.039 | 0.56 | 3 | 4 | 1 |
| HD162020 | 0.074 | 0.75 | 1 | 0.030 | 0.41 | 2 | 3 | 0.91 |
| HD130322 | 0.088 | 0.79 | 1 | 0.032 | 0.36 | 3 | 5 | 1 |
| HD108147 | 0.102 | 1.27 | 1 | 0.051 | 0.50 | 3 | 4 | 0.89 |
| HD38529b | 0.129 | 1.39 | 1 | 0.056 | 0.43 | 2 | 3 | 0.97 |
| HD75732b | 0.115 | 0.95 | 1 | 0.038 | 0.33 | 3 | 5 | 0.92 |
| HD195019 | 0.140 | 1.02 | 2 | 0.163 | 1.17 | 16 | 15 | 1.02 |
| HD6434 | 0.150 | 0.79 | 2 | 0.126 | 0.84 | 15 | 16 | 0.96 |
| HD192263 | 0.150 | 0.79 | 2 | 0.126 | 0.84 | 15 | 16 | 0.96 |
| GJ876c | 0.130 | 0.32 | 3 | 0.115 | 0.89 | 15 | 16 | 1.01 |
| HD37124b | 0.181 | 0.91 | 2 | 0.146 | 0.80 | 15 | 17 | 1.03 |
| HD143761 | 0.220 | 0.95 | 2 | 0.152 | 0.69 | 5 | 6 | 0.99 |
| HD75732c | 0.240 | 0.95 | 2 | 0.152 | 0.63 | 4 | 5 | 0.99 |
| HD74156b | 0.280 | 1.27 | 2 | 0.203 | 0.73 | 5 | 6 | 1.05 |
| HD168443b | 0.295 | 1.01 | 2 | 0.162 | 0.55 | 3 | 4 | 0.97 |
| GJ876b | 0.210 | 0.32 | 4 | 0.205 | 0.98 | 1 | 1 | 0.98 |
| HD3651 | 0.284 | 0.79 | 3 | 0.284 | 1.00 | 1 | 1 | 1 |
| HD121504 | 0.320 | 1.18 | 2 | 0.189 | 0.59 | 3 | 4 | 1.05 |
| HD178911 | 0.326 | 0.87 | 3 | 0.313 | 0.96 | 1 | 1 | 0.96 |
| HD16141 | 0.350 | 1.00 | 3 | 0.360 | 1.03 | 1 | 1 | 1.03 |
| HD114762 | 0.350 | 0.82 | 3 | 0.295 | 0.84 | 15 | 16 | 0.96 |
| HD80606 | 0.469 | 1.10 | 3 | 0.396 | 0.84 | 15 | 16 | 0.96 |
| HD117176 | 0.480 | 1.10 | 3 | 0.396 | 0.83 | 15 | 16 | 0.94 |
| HD216770 | 0.460 | 0.90 | 3 | 0.324 | 0.70 | 5 | 6 | 1.01 |

| Star Name | R | M | n | R1 | R1/R | r | s | R2/R |
|---|---|---|---|---|---|---|---|---|
| HD52265 | 0.49 | 1.13 | 3 | 0.41 | 0.83 | 15 | 16 | 0.94 |
| HD73526 | 0.65 | 1.02 | 4 | 0.65 | 1 | 1 | 1 | 1.00 |
| HD82943c | 0.73 | 1.05 | 4 | 0.67 | 0.92 | 16 | 17 | 1.04 |
| HD8574 | 0.77 | 1.17 | 4 | 0.75 | 0.97 | 1 | 1 | 0.97 |
| HD169830 | 0.82 | 1.40 | 4 | 0.90 | 1.09 | 17 | 16 | 0.97 |
| HD9826c | 0.83 | 1.30 | 4 | 0.83 | 1.00 | 1 | 1 | 1.00 |
| HD202206 | 0.83 | 1.15 | 4 | 0.74 | 0.89 | 15 | 16 | 1.01 |
| HD89744 | 0.89 | 1.40 | 4 | 0.9 | 1.01 | 1 | 1 | 1.01 |
| HD134987 | 0.81 | 1.05 | 4 | 0.67 | 0.83 | 15 | 16 | 0.94 |
| HD12661b | 0.82 | 1.07 | 4 | 0.68 | 0.84 | 15 | 16 | 0.95 |
| HD150706 | 0.82 | 0.98 | 5 | 0.98 | 1.20 | 16 | 15 | 1.05 |
| HD40979 | 0.81 | 1.08 | 4 | 0.69 | 0.85 | 15 | 16 | 0.97 |
| HD92788 | 0.95 | 1.06 | 5 | 1.06 | 1.12 | 16 | 15 | 0.98 |
| HD142 | 0.97 | 1.10 | 5 | 1.1 | 1.13 | 16 | 15 | 1.00 |
| HD28185 | 1.03 | 0.99 | 5 | 0.99 | 0.96 | 1 | 1 | 0.96 |
| HD142415 | 1.07 | 1.03 | 5 | 1.03 | 0.96 | 1 | 1 | 0.96 |
| HD108874b | 1.06 | 1.00 | 5 | 1.00 | 0.94 | 1 | 1 | 0.94 |
| HD4203 | 1.09 | 1.06 | 5 | 1.06 | 0.97 | 1 | 1 | 0.97 |
| HD177830 | 1.14 | 1.17 | 5 | 1.17 | 1.03 | 1 | 1 | 1.03 |
| HD128311b | 1.02 | 0.80 | 6 | 1.15 | 1.13 | 1 | 1 | 1.13 |
| HD27442 | 1.18 | 1.20 | 5 | 1.20 | 1.02 | 1 | 1 | 1.02 |
| HD210277 | 1.12 | 0.99 | 5 | 0.99 | 0.88 | 15 | 16 | 1.01 |
| HD82943b | 1.16 | 1.05 | 5 | 1.05 | 0.91 | 15 | 16 | 1.03 |
| HD20367 | 1.25 | 1.17 | 5 | 1.17 | 0.94 | 1 | 1 | 0.94 |
| HD114783 | 1.19 | 0.92 | 6 | 1.32 | 1.11 | 1 | 1 | 1.11 |
| HD137759 | 1.28 | 1.05 | 5 | 1.05 | 0.82 | 15 | 17 | 1.05 |
| HD19994 | 1.42 | 1.34 | 5 | 1.34 | 0.94 | 1 | 1 | 0.94 |
| HD147513 | 1.26 | 1.11 | 5 | 1.11 | 0.88 | 15 | 16 | 1.00 |
| HD222582 | 1.35 | 1.00 | 6 | 1.44 | 1.07 | 1 | 1 | 1.07 |
| HD65216 | 1.31 | 0.92 | 6 | 1.32 | 1.01 | 1 | 1 | 1.01 |
| HD141937 | 1.52 | 1.10 | 6 | 1.58 | 1.04 | 1 | 1 | 1.04 |
| HD41004A | 1.31 | 0.70 | 7 | 1.37 | 1.05 | 1 | 1 | 1.05 |
| HD160691b | 1.87 | 1.08 | 7 | 2.12 | 1.13 | 16 | 15 | 0.99 |


| Star Name | R | M | n | R1 | R1/R | r | s | R2/R |
|---|---|---|---|---|---|---|---|---|
| HD52265 | 0.49 | 1.13 | 3 | 0.41 | 0.83 | 15 | 16 | 0.94 |
| HD73526 | 0.65 | 1.02 | 4 | 0.65 | 1 | 1 | 1 | 1.00 |
| HD82943c | 0.73 | 1.05 | 4 | 0.67 | 0.92 | 16 | 17 | 1.04 |
| HD8574 | 0.77 | 1.17 | 4 | 0.75 | 0.97 | 1 | 1 | 0.97 |
| HD169830 | 0.82 | 1.40 | 4 | 0.90 | 1.09 | 17 | 16 | 0.97 |
| HD9826c | 0.83 | 1.30 | 4 | 0.83 | 1.00 | 1 | 1 | 1.00 |
| HD202206 | 0.83 | 1.15 | 4 | 0.74 | 0.89 | 15 | 16 | 1.01 |
| HD89744 | 0.89 | 1.40 | 4 | 0.9 | 1.01 | 1 | 1 | 1.01 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| HD134987 | 0.81 | 1.05 | 4 | 0.67 | 0.83 | 15 | 16 | 0.94 |
| HD12661b | 0.82 | 1.07 | 4 | 0.68 | 0.84 | 15 | 16 | 0.95 |
| HD150706 | 0.82 | 0.98 | 5 | 0.98 | 1.20 | 16 | 15 | 1.05 |
| HD40979 | 0.81 | 1.08 | 4 | 0.69 | 0.85 | 15 | 16 | 0.97 |
| HD92788 | 0.95 | 1.06 | 5 | 1.06 | 1.12 | 16 | 15 | 0.98 |
| HD142 | 0.97 | 1.10 | 5 | 1.1 | 1.13 | 16 | 15 | 1.00 |
| HD28185 | 1.03 | 0.99 | 5 | 0.99 | 0.96 | 1 | 1 | 0.96 |
| HD142415 | 1.07 | 1.03 | 5 | 1.03 | 0.96 | 1 | 1 | 0.96 |
| HD108874b | 1.06 | 1.00 | 5 | 1.00 | 0.94 | 1 | 1 | 0.94 |
| HD4203 | 1.09 | 1.06 | 5 | 1.06 | 0.97 | 1 | 1 | 0.97 |
| HD177830 | 1.14 | 1.17 | 5 | 1.17 | 1.03 | 1 | 1 | 1.03 |
| HD128311b | 1.02 | 0.80 | 6 | 1.15 | 1.13 | 1 | 1 | 1.13 |
| HD27442 | 1.18 | 1.20 | 5 | 1.20 | 1.02 | 1 | 1 | 1.02 |
| HD210277 | 1.12 | 0.99 | 5 | 0.99 | 0.88 | 15 | 16 | 1.01 |
| HD82943b | 1.16 | 1.05 | 5 | 1.05 | 0.91 | 15 | 16 | 1.03 |
| HD20367 | 1.25 | 1.17 | 5 | 1.17 | 0.94 | 1 | 1 | 0.94 |
| HD114783 | 1.19 | 0.92 | 6 | 1.32 | 1.11 | 1 | 1 | 1.11 |
| HD137759 | 1.28 | 1.05 | 5 | 1.05 | 0.82 | 15 | 17 | 1.05 |
| HD19994 | 1.42 | 1.34 | 5 | 1.34 | 0.94 | 1 | 1 | 0.94 |
| HD147513 | 1.26 | 1.11 | 5 | 1.11 | 0.88 | 15 | 16 | 1.00 |
| HD222582 | 1.35 | 1.00 | 6 | 1.44 | 1.07 | 1 | 1 | 1.07 |
| HD65216 | 1.31 | 0.92 | 6 | 1.32 | 1.01 | 1 | 1 | 1.01 |
| HD141937 | 1.52 | 1.10 | 6 | 1.58 | 1.04 | 1 | 1 | 1.04 |
| HD41004A | 1.31 | 0.70 | 7 | 1.37 | 1.05 | 1 | 1 | 1.05 |
| HD160691b | 1.87 | 1.08 | 7 | 2.12 | 1.13 | 16 | 15 | 0.99 |

| Star Name | R | M | n | R1 | R1/R | r | s | R2/R |
|---|---|---|---|---|---|---|---|---|
| HD23079 | 1.65 | 1.10 | 6 | 1.58 | 0.96 | 1 | 1 | 0.96 |
| HD186427 | 1.67 | 1.01 | 6 | 1.45 | 0.87 | 15 | 16 | 0.99 |
| HD4208 | 1.67 | 0.93 | 7 | 1.82 | 1.09 | 16 | 15 | 0.96 |
| HD114386 | 1.62 | 0.68 | 8 | 1.74 | 1.07 | 17 | 16 | 0.95 |
| HD213240 | 2.03 | 1.22 | 6 | 1.76 | 0.87 | 15 | 16 | 0.98 |
| HD10647 | 2.10 | 1.07 | 7 | 2.10 | 1.00 | 1 | 1 | 1 |
| HD10697 | 2.13 | 1.10 | 7 | 2.16 | 1.01 | 1 | 1 | 1.01 |
| HD95128b | 2.09 | 1.03 | 7 | 2.02 | 0.97 | 1 | 1 | 0.97 |
| HD190228 | 2.00 | 0.83 | 8 | 2.12 | 1.06 | 1 | 1 | 1.06 |
| HD114729 | 2.08 | 0.93 | 7 | 1.82 | 0.88 | 15 | 16 | 1 |
| HD111232 | 1.97 | 0.78 | 8 | 2.00 | 1.01 | 1 | 1 | 1.01 |
| HD2039 | 2.19 | 0.98 | 7 | 1.92 | 0.88 | 15 | 16 | 1 |
| HD136118 | 2.40 | 1.24 | 7 | 2.43 | 1.01 | 1 | 1 | 1.01 |
| HD50554 | 2.32 | 1.07 | 7 | 2.09 | 0.9 | 15 | 16 | 1.02 |
| HD9826d | 2.53 | 1.30 | 7 | 2.55 | 1.01 | 1 | 1 | 1.01 |
| HD196050 | 2.43 | 1.10 | 7 | 2.16 | 0.89 | 15 | 16 | 1.01 |
| HD216437 | 2.43 | 1.07 | 8 | 2.74 | 1.13 | 17 | 15 | 0.88 |
| HD216435 | 2.70 | 1.25 | 7 | 2.45 | 0.91 | 1 | 1 | 0.91 |
| HD169830c | 2.75 | 1.40 | 7 | 2.74 | 1 | 1 | 1 | 1 |
| HD106252 | 2.54 | 0.96 | 8 | 2.46 | 0.97 | 1 | 1 | 0.97 |
| HD12661c | 2.60 | 1.07 | 8 | 2.74 | 1.05 | 1 | 1 | 1.05 |
| HD23596 | 2.86 | 1.30 | 7 | 2.55 | 0.89 | 15 | 16 | 1.01 |
| HD168443c | 2.87 | 1.01 | 8 | 2.59 | 0.9 | 15 | 16 | 1.03 |
| HD145675 | 2.85 | 1.00 | 8 | 2.56 | 0.9 | 15 | 16 | 1.02 |
| HD11964b | 3.10 | 1.10 | 8 | 2.82 | 0.91 | 16 | 17 | 1.03 |
| HD39091 | 3.29 | 1.10 | 9 | 3.56 | 1.08 | 17 | 16 | 0.96 |
| HD38529c | 3.71 | 1.39 | 8 | 3.56 | 0.96 | 1 | 1 | 0.96 |
| HD70642 | 3.30 | 1.00 | 9 | 3.24 | 0.98 | 1 | 1 | 0.98 |
| HD33636 | 3.56 | 0.99 | 9 | 3.21 | 0.9 | 15 | 16 | 1.03 |
| HD95128c | 3.73 | 1.03 | 10 | 4.12 | 1.1 | 16 | 15 | 0.97 |
| HD190360 | 3.65 | 0.96 | 10 | 3.84 | 1.05 | 1 | 1 | 1.05 |
| HD74156c | 3.82 | 1.27 | 9 | 4.11 | 1.08 | 1 | 1 | 1.08 |
| HD22049 | 3.54 | 0.80 | 11 | 3.87 | 1.09 | 16 | 15 | 0.96 |
| HD30177 | 3.86 | 0.95 | 10 | 3.80 | 0.98 | 1 | 1 | 0.98 |
| HD89307 | 4.15 | 0.95 | 10 | 3.80 | 0.92 | 1 | 1 | 0.92 |
| HD72659 | 4.50 | 0.95 | 11 | 4.60 | 1.02 | 1 | 1 | 1.02 |
| HD75732d | 5.90 | 0.95 | 13 | 6.42 | 1.09 | 16 | 15 | 0.96 |

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