

# Introduction

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# 1 Background

*T(opological) G(eometro)D(ynamics)* is one of the many attempts to find a unified description of basic interactions. The development of the basic ideas of TGD to a relatively stable form took time of about half decade [16]. The great challenge is to construct a mathematical theory around these physically very attractive ideas and I have devoted the last twenty-three years for the realization of this dream and this has resulted in seven online books [1, 2, 4, 5, 3, 6, 7] about TGD and eight online books about TGD inspired theory of consciousness and of quantum biology [10, 8, 9, 13, 11, 12, 14, 15].

Quantum T(opological)D(ynamics) as a classical spinor geometry for infinite-dimensional configuration space, p-adic numbers and quantum TGD, and TGD inspired theory of consciousness have been for last decade of the second millenium the basic three strongly interacting threads in the tapestry of quantum TGD.

For few yeas ago the discussions with Tony Smith generated a fourth thread which deserves the name 'TGD as a generalized number theory'. The work with Riemann hypothesis made time ripe for realization that the notion of infinite primes could provide, not only a reformulation, but a deep generalization of quantum TGD. This led to a thorough and extremely fruitful revision of the basic views about what the final form and physical content of quantum TGD might be.

The fifth thread came with the realization that by quantum classical correspondence TGD predicts an infinite hierarchy of macroscopic quantum systems with increasing sizes, that it is not at all clear whether standard quantum mechanics can accommodate this hierarchy, and that a dynamical quantized Planck constant might be necessary and certainly possible in TGD framework. The identification of hierarchy of Planck constants whose values TGD "predicts" in terms of dark matter hierarchy would be natural. This also led to a solution of a long standing puzzle: what is the proper interpretation of the predicted fractal hierarchy of long ranged classical electro-weak and color gauge fields. Quantum classical correspondences allows only single answer: there is infinite hierarchy of p-adically scaled up variants of standard model physics and for each of them also dark hierarchy. Thus TGD Universe would be fractal in very abstract and deep sense.

TGD forces the generalization of physics to a quantum theory of consciousness, and represent TGD as a generalized number theory vision leads naturally to the emergence of p-adic physics as physics of cognitive representations. The seven online books [1, 2, 4, 5, 3, 6, 7] about TGD and eight online books about TGD inspired theory of consciousness and of quantum biology [10, 8, 9, 13, 11, 12, 14, 15] are warmly recommended to the interested reader.

## 2 Basic Ideas of TGD

The basic physical picture behind TGD was formed as a fusion of two rather disparate approaches: namely TGD is as a Poincare invariant theory of gravitation and TGD as a generalization of the old-fashioned string model.

### 2.1 TGD as a Poincare invariant theory of gravitation

The first approach was born as an attempt to construct a Poincare invariant theory of gravitation. Space-time, rather than being an abstract manifold endowed with a pseudo-Riemannian structure, is regarded as a surface in the 8-dimensional space  $H = M_+^4 \times CP_2$ , where  $M_+^4$  denotes the interior of the future light cone of the Minkowski space (to be referred as light cone in the sequel) and  $CP_2 = SU(3)/U(2)$  is the complex projective space of two complex dimensions [17, 18, 19, 20]. The identification of the space-time as a submanifold [21, 22] of  $M^4 \times CP_2$  leads to an exact Poincare invariance and solves the conceptual difficulties related to the definition of the energy-momentum in General Relativity [Misner-Thorne-Wheeler, Logunov *et al*]. The actual choice  $H = M_+^4 \times CP_2$

implies the breaking of the Poincare invariance in the cosmological scales but only at the quantum level. It soon however turned out that submanifold geometry, being considerably richer in structure than the abstract manifold geometry, leads to a geometrization of all basic interactions. First, the geometrization of the elementary particle quantum numbers is achieved. The geometry of  $CP_2$  explains electro-weak and color quantum numbers. The different H-chiralities of  $H$ -spinors correspond to the conserved baryon and lepton numbers. Secondly, the geometrization of the field concept results. The projections of the  $CP_2$  spinor connection, Killing vector fields of  $CP_2$  and of  $H$ -metric to four-surface define classical electro-weak, color gauge fields and metric in  $X^4$ .

## 2.2 TGD as a generalization of the hadronic string model

The second approach was based on the generalization of the mesonic string model describing mesons as strings with quarks attached to the ends of the string. In the 3-dimensional generalization 3-surfaces correspond to free particles and the boundaries of the 3- surface correspond to partons in the sense that the quantum numbers of the elementary particles reside on the boundaries. Various boundary topologies (number of handles) correspond to various fermion families so that one obtains an explanation for the known elementary particle quantum numbers. This approach leads also to a natural topological description of the particle reactions as topology changes: for instance, two-particle decay corresponds to a decay of a 3-surface to two disjoint 3-surfaces.

## 2.3 Fusion of the two approaches via a generalization of the space-time concept

The problem is that the two approaches seem to be mutually exclusive since the orbit of a particle like 3-surface defines 4-dimensional surface, which differs drastically from the topologically trivial macroscopic space-time of General Relativity. The unification of these approaches forces a considerable generalization of the conventional space-time concept. First, the topologically trivial 3-space of General Relativity is replaced with a "topological condensate" containing matter as particle like 3-surfaces "glued" to the topologically trivial background 3-space by connected sum operation. Secondly, the assumption about connectedness of the 3-space is given up. Besides the "topological condensate" there is "vapor phase" that is a "gas" of particle like 3-surfaces (counterpart of the "baby universes" of GRT) and the nonconservation of energy in GRT corresponds to the transfer of energy between the topological condensate and vapor phase.

# 3 The five threads in the development of quantum TGD

The development of TGD has involved four strongly interacting threads: physics as infinite-dimensional geometry; p-adic physics; TGD inspired theory of consciousness and TGD as a generalized number theory. In the following these five threads are briefly described.

## 3.1 Quantum TGD as configuration space spinor geometry

A turning point in the attempts to formulate a mathematical theory was reached after seven years from the birth of TGD. The great insight was "Do not quantize". The basic ingredients to the new approach have served as the basic philosophy for the attempt to construct Quantum TGD since then and are the following ones:

a) Quantum theory for extended particles is free(!), classical(!) field theory for a generalized Schrödinger amplitude in the configuration space  $CH$  consisting of all possible 3-surfaces in  $H$ . "All possible" means that surfaces with arbitrary many disjoint components and with arbitrary

internal topology and also singular surfaces topologically intermediate between two different manifold topologies are included. Particle reactions are identified as topology changes [23, 24, 25]. For instance, the decay of a 3-surface to two 3-surfaces corresponds to the decay  $A \rightarrow B + C$ . Classically this corresponds to a path of configuration space leading from 1-particle sector to 2-particle sector. At quantum level this corresponds to the dispersion of the generalized Schrödinger amplitude localized to 1-particle sector to two-particle sector. All coupling constants should result as predictions of the theory since no nonlinearities are introduced.

b) Configuration space is endowed with the metric and spinor structure so that one can define various metric related differential operators, say Dirac operator, appearing in the field equations of the theory.

### 3.2 p-Adic TGD

The p-adic thread emerged for roughly ten years ago as a dim hunch that p-adic numbers might be important for TGD. Experimentation with p-adic numbers led to the notion of canonical identification mapping reals to p-adics and vice versa. The breakthrough came with the successful p-adic mass calculations using p-adic thermodynamics for Super-Virasoro representations with the super-Kac-Moody algebra associated with a Lie-group containing standard model gauge group. Although the details of the calculations have varied from year to year, it was clear that p-adic physics reduces not only the ratio of proton and Planck mass, the great mystery number of physics, but all elementary particle mass scales, to number theory if one assumes that primes near prime powers of two are in a physically favored position. Why this is the case, became one of the key puzzles and led to a number of arguments with a common gist: evolution is present already at the elementary particle level and the primes allowed by the p-adic length scale hypothesis are the fittest ones.

It became very soon clear that p-adic topology is not something emerging in Planck length scale as often believed, but that there is an infinite hierarchy of p-adic physics characterized by p-adic length scales varying to even cosmological length scales. The idea about the connection of p-adics with cognition motivated already the first attempts to understand the role of the p-adics and inspired 'Universe as Computer' vision but time was not ripe to develop this idea to anything concrete (p-adic numbers are however in a central role in TGD inspired theory of consciousness). It became however obvious that the p-adic length scale hierarchy somehow corresponds to a hierarchy of intelligences and that p-adic prime serves as a kind of intelligence quotient. Ironically, the almost obvious idea about p-adic regions as cognitive regions of space-time providing cognitive representations for real regions had to wait for almost a decade for the access into my consciousness.

There were many interpretational and technical questions crying for a definite answer. What is the relationship of p-adic non-determinism to the classical non-determinism of the basic field equations of TGD? Are the p-adic space-time region genuinely p-adic or does p-adic topology only serve as an effective topology? If p-adic physics is direct image of real physics, how the mapping relating them is constructed so that it respects various symmetries? Is the basic physics p-adic or real (also real TGD seems to be free of divergences) or both? If it is both, how should one glue the physics in different number field together to get *The Physics*? Should one perform p-adicization also at the level of the configuration space of 3-surfaces? Certainly the p-adicization at the level of super-conformal representation is necessary for the p-adic mass calculations. Perhaps the most basic and most irritating technical problem was how to precisely define p-adic definite integral which is a crucial element of any variational principle based formulation of the field equations. Here the frustration was not due to the lack of solution but due to the too large number of solutions to the problem, a clear symptom for the sad fact that clever inventions rather than real discoveries might be in question.

Despite these frustrating uncertainties, the number of the applications of the poorly defined p-adic physics grew steadily and the applications turned out to be relatively stable so that it

was clear that the solution to these problems must exist. It became only gradually clear that the solution of the problems might require going down to a deeper level than that represented by reals and p-adics.

### 3.3 TGD as a generalization of physics to a theory consciousness

General coordinate invariance forces the identification of quantum jump as quantum jump between entire deterministic quantum histories rather than time=constant snapshots of single history. The new view about quantum jump forces a generalization of quantum measurement theory such that observer becomes part of the physical system. Thus a general theory of consciousness is unavoidable outcome. This theory is developed in detail in the books [10, 8, 9, 13, 11, 12, 14, 15].

#### 3.3.1 Quantum jump as a moment of consciousness

The identification of quantum jump between deterministic quantum histories (configuration space spinor fields) as a moment of consciousness defines microscopic theory of consciousness. Quantum jump involves the steps

$$\Psi_i \rightarrow U\Psi_i \rightarrow \Psi_f \quad ,$$

where  $U$  is informational "time development" operator, which is unitary like the S-matrix characterizing the unitary time evolution of quantum mechanics.  $U$  is however only formally analogous to Schrödinger time evolution of infinite duration although there is *no* real time evolution involved. It is not however clear whether one should regard U-matrix and S-matrix as two different things or not:  $U$ -matrix is a completely universal object characterizing the dynamics of evolution by self-organization whereas S-matrix is a highly context dependent concept in wave mechanics and in quantum field theories where it at least formally represents unitary time translation operator at the limit of an infinitely long interaction time. The S-matrix understood in the spirit of superstring models is however something very different and could correspond to U-matrix.

The requirement that quantum jump corresponds to a measurement in the sense of quantum field theories implies that each quantum jump involves localization in zero modes which parameterize also the possible choices of the quantization axes. Thus the selection of the quantization axes performed by the Cartesian outsider becomes now a part of quantum theory. Together these requirements imply that the final states of quantum jump correspond to quantum superpositions of space-time surfaces which are macroscopically equivalent. Hence the world of conscious experience looks classical. At least formally quantum jump can be interpreted also as a quantum computation in which matrix  $U$  represents unitary quantum computation which is however not identifiable as unitary translation in time direction and cannot be 'engineered'.

#### 3.3.2 The notion of self

The concept of self is absolutely essential for the understanding of the macroscopic and macro-temporal aspects of consciousness. Self corresponds to a subsystem able to remain un-entangled under the sequential informational 'time evolutions'  $U$ . Exactly vanishing entanglement is practically impossible in ordinary quantum mechanics and it might be that 'vanishing entanglement' in the condition for self-property should be replaced with 'subcritical entanglement'. On the other hand, if space-time decomposes into p-adic and real regions, and if entanglement between regions representing physics in different number fields vanishes, space-time indeed decomposes into selves in a natural manner.

It is assumed that the experiences of the self after the last 'wake-up' sum up to single average experience. This means that subjective memory is identifiable as conscious, immediate short term memory. Selves form an infinite hierarchy with the entire Universe at the top. Self can be also

interpreted as mental images: our mental images are selves having mental images and also we represent mental images of a higher level self. A natural hypothesis is that self  $S$  experiences the experiences of its subselves as kind of abstracted experience: the experiences of subselves  $S_i$  are not experienced as such but represent kind of averages  $\langle S_{ij} \rangle$  of sub-subselves  $S_{ij}$ . Entanglement between selves, most naturally realized by the formation of join along boundaries bonds between cognitive or material space-time sheets, provides a possible a mechanism for the fusion of selves to larger selves (for instance, the fusion of the mental images representing separate right and left visual fields to single visual field) and forms wholes from parts at the level of mental images.

### 3.3.3 Relationship to quantum measurement theory

The third basic element relates TGD inspired theory of consciousness to quantum measurement theory. The assumption that localization occurs in zero modes in each quantum jump implies that the world of conscious experience looks classical. It also implies the state function reduction of the standard quantum measurement theory as the following arguments demonstrate (it took incredibly long time to realize this almost obvious fact!).

a) The standard quantum measurement theory a la von Neumann involves the interaction of brain with the measurement apparatus. If this interaction corresponds to entanglement between microscopic degrees of freedom  $m$  with the macroscopic effectively classical degrees of freedom  $M$  characterizing the reading of the measurement apparatus coded to brain state, then the reduction of this entanglement in quantum jump reproduces standard quantum measurement theory provide the unitary time evolution operator  $U$  acts as flow in zero mode degrees of freedom and correlates completely some orthonormal basis of configuration space spinor fields in non-zero modes with the values of the zero modes. The flow property guarantees that the localization is consistent with unitarity: it also means 1-1 mapping of quantum state basis to classical variables (say, spin direction of the electron to its orbit in the external magnetic field).

b) Since zero modes represent classical information about the geometry of space-time surface (shape, size, classical Kähler field,...), they have interpretation as effectively classical degrees of freedom and are the TGD counterpart of the degrees of freedom  $M$  representing the reading of the measurement apparatus. The entanglement between quantum fluctuating non-zero modes and zero modes is the TGD counterpart for the  $m - M$  entanglement. Therefore the localization in zero modes is equivalent with a quantum jump leading to a final state where the measurement apparatus gives a definite reading.

This simple prediction is of utmost theoretical importance since the black box of the quantum measurement theory is reduced to a fundamental quantum theory. This reduction is implied by the replacement of the notion of a point like particle with particle as a 3-surface. Also the infinite-dimensionality of the zero mode sector of the configuration space of 3-surfaces is absolutely essential. Therefore the reduction is a triumph for quantum TGD and favors TGD against string models.

Standard quantum measurement theory involves also the notion of state preparation which reduces to the notion of self measurement. Each localization in zero modes is followed by a cascade of self measurements leading to a product state. This process is obviously equivalent with the state preparation process. Self measurement is governed by the so called Negentropy Maximization Principle (NMP) stating that the information content of conscious experience is maximized. In the self measurement the density matrix of some subsystem of a given self localized in zero modes (after ordinary quantum measurement) is measured. The self measurement takes place for that subsystem of self for which the reduction of the entanglement entropy is maximal in the measurement. In p-adic context NMP can be regarded as the variational principle defining the dynamics of cognition. In real context self measurement could be seen as a repair mechanism allowing the system to fight against quantum thermalization by reducing the entanglement for the subsystem for which it is largest (fill the largest hole first in a leaking boat).

### 3.3.4 Selves self-organize

The fourth basic element is quantum theory of self-organization based on the identification of quantum jump as the basic step of self-organization [I1]. Quantum entanglement gives rise to the generation of long range order and the emergence of longer p-adic length scales corresponds to the emergence of larger and larger coherent dynamical units and generation of a slaving hierarchy. Energy (and quantum entanglement) feed implying entropy feed is a necessary prerequisite for quantum self-organization. Zero modes represent fundamental order parameters and localization in zero modes implies that the sequence of quantum jumps can be regarded as hopping in the zero modes so that Haken's classical theory of self organization applies almost as such. Spin glass analogy is a further important element: self-organization of self leads to some characteristic pattern selected by dissipation as some valley of the "energy" landscape.

Dissipation can be regarded as the ultimate Darwinian selector of both memes and genes. The mathematically ugly irreversible dissipative dynamics obtained by adding phenomenological dissipation terms to the reversible fundamental dynamical equations derivable from an action principle can be understood as a phenomenological description replacing in a well defined sense the series of reversible quantum histories with its envelope.

### 3.3.5 Classical non-determinism of Kähler action

The fifth basic element are the concepts of association sequence and cognitive space-time sheet. The huge vacuum degeneracy of the Kähler action suggests strongly that the absolute minimum space-time is not always unique. For instance, a sequence of bifurcations can occur so that a given space-time branch can be fixed only by selecting a finite number of 3-surfaces with time like(!) separations on the orbit of 3-surface. Quantum classical correspondence suggest an alternative formulation. Space-time surface decomposes into maximal deterministic regions and their temporal sequences have interpretation a space-time correlate for a sequence of quantum states defined by the initial (or final) states of quantum jumps. This is consistent with the fact that the variational principle selects preferred extremals of Kähler action as generalized Bohr orbits.

In the case that non-determinism is located to a finite time interval and is microscopic, this sequence of 3-surfaces has interpretation as a simulation of a classical history, a geometric correlate for contents of consciousness. When non-determinism has long lasting and macroscopic effect one can identify it as volitional non-determinism associated with our choices. Association sequences relate closely with the cognitive space-time sheets defined as space-time sheets having finite time duration and psychological time can be identified as a temporal center of mass coordinate of the cognitive space-time sheet. The gradual drift of the cognitive space-time sheets to the direction of future force by the geometry of the future light cone explains the arrow of psychological time.

### 3.3.6 p-Adic physics as physics of cognition and intentionality

The sixth basic element adds a physical theory of cognition to this vision. TGD space-time decomposes into regions obeying real and p-adic topologies labelled by primes  $p = 2, 3, 5, \dots$  p-Adic regions obey the same field equations as the real regions but are characterized by p-adic non-determinism since the functions having vanishing p-adic derivative are pseudo constants which are piecewise constant functions. Pseudo constants depend on a finite number of positive binary digits of arguments just like numerical predictions of any theory always involve decimal cutoff. This means that p-adic space-time regions are obtained by gluing together regions for which integration constants are genuine constants. The natural interpretation of the p-adic regions is as cognitive representations of real physics. The freedom of imagination is due to the p-adic non-determinism. p-Adic regions perform mimicry and make possible for the Universe to form cognitive representations about itself. p-Adic physics space-time sheets serve also as correlates for intentional action.

A more more precise formulation of this vision requires a generalization of the number concept obtained by fusing reals and p-adic number fields along common rationals (in the case of algebraic extensions among common algebraic numbers). This picture is discussed in [E1]. The application this notion at the level of the imbedding space implies that imbedding space has a book like structure with various variants of the imbedding space glued together along common rationals (algebraics). The implication is that genuinely p-adic numbers (non-rationals) are strictly infinite as real numbers so that most points of p-adic space-time sheets are at real infinity, outside the cosmos, and that the projection to the real imbedding space is discrete set of rationals (algebraics). Hence cognition and intentionality are almost completely outside the real cosmos and touch it at a discrete set of points only.

This view implies also that purely local p-adic physics codes for the p-adic fractality characterizing long range real physics and provides an explanation for p-adic length scale hypothesis stating that the primes  $p \simeq 2^k$ ,  $k$  integer are especially interesting. It also explains the long range correlations and short term chaos characterizing intentional behavior and explains why the physical realizations of cognition are always discrete (say in the case of numerical computations). Furthermore, a concrete quantum model for how intentions are transformed to actions emerges.

The discrete real projections of p-adic space-time sheets serve also space-time correlate for a logical thought. It is very natural to assign to p-adic binary digits a  $p$ -valued logic but as such this kind of logic does not have any reasonable identification. p-Adic length scale hypothesis suggest that the  $p = 2^k - n$  binary digits represent a Boolean logic  $B^k$  with  $k$  elementary statements (the points of the  $k$ -element set in the set theoretic realization) with  $n$  taboos which are constrained to be identically true.

### 3.4 TGD as a generalized number theory

Quantum T(opological)D(ynamics) as a classical spinor geometry for infinite-dimensional configuration space, p-adic numbers and quantum TGD, and TGD inspired theory of consciousness, have been for last ten years the basic three strongly interacting threads in the tapestry of quantum TGD. For few yeas ago the discussions with Tony Smith generated a fourth thread which deserves the name 'TGD as a generalized number theory'. It relies on the notion of number theoretic compactification stating that space-time surfaces can be regarded either as hyper-quaternionic, and thus maximally associative, 4-surfaces in  $M^8$  identifiable as space of hyper-octonions or as surfaces in  $M^4 \times CP_2$  [E2].

The discovery of the hierarchy of infinite primes and their correspondence with a hierarchy defined by a repeatedly second quantized arithmetic quantum field theory gave a further boost for the speculations about TGD as a generalized number theory. The work with Riemann hypothesis led to further ideas.

After the realization that infinite primes can be mapped to polynomials representable as surfaces geometrically, it was clear how TGD might be formulated as a generalized number theory with infinite primes forming the bridge between classical and quantum such that real numbers, p-adic numbers, and various generalizations of p-adics emerge dynamically from algebraic physics as various completions of the algebraic extensions of rational (hyper-)quaternions and (hyper-)octonions. Complete algebraic, topological and dimensional democracy would characterize the theory.

What is especially satisfying is that p-adic and real regions of the space-time surface could emerge automatically as solutions of the field equations. In the space-time regions where the solutions of field equations give rise to in-admissible complex values of the imbedding space coordinates, p-adic solution can exist for some values of the p-adic prime. The characteristic non-determinism of the p-adic differential equations suggests strongly that p-adic regions correspond to 'mind stuff', the regions of space-time where cognitive representations reside. This interpretation implies that

p-adic physics is physics of cognition. Since Nature is probably extremely brilliant simulator of Nature, the natural idea is to study the p-adic physics of the cognitive representations to derive information about the real physics. This view encouraged by TGD inspired theory of consciousness clarifies difficult interpretational issues and provides a clear interpretation for the predictions of p-adic physics.

### 3.5 Dynamical quantized Planck constant and dark matter hierarchy

By quantum classical correspondence space-time sheets can be identified as quantum coherence regions. Hence the fact that they have all possible size scales more or less unavoidably implies that Planck constant must be quantized and have arbitrarily large values. If one accepts this then also the idea about dark matter as a macroscopic quantum phase characterized by an arbitrarily large value of Planck constant emerges naturally as does also the interpretation for the long ranged classical electro-weak and color fields predicted by TGD. Rather seldom the evolution of ideas follows simple linear logic, and this was the case also now. In any case, this vision represents the fifth, relatively new thread in the evolution of TGD and the ideas involved are still evolving.

#### 3.5.1 Dark matter as large $\hbar$ phase

D. Da Rocha and Laurent Nottale [35] have proposed that Schrödinger equation with Planck constant  $\hbar$  replaced with what might be called gravitational Planck constant  $\hbar_{gr} = \frac{GmM}{v_0}$  ( $\hbar = c = 1$ ).  $v_0$  is a velocity parameter having the value  $v_0 = 144.7 \pm .7$  km/s giving  $v_0/c = 4.6 \times 10^{-4}$ . This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of  $v_0$  seem to appear. The support for the hypothesis coming from empirical data is impressive.

Nottale and Da Rocha believe that their Schrödinger equation results from a fractal hydrodynamics. Many-sheeted space-time however suggests astrophysical systems are not only quantum systems at larger space-time sheets but correspond to a gigantic value of gravitational Planck constant. The gravitational (ordinary) Schrödinger equation would provide a solution of the black hole collapse (IR catastrophe) problem encountered at the classical level. The resolution of the problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale [D6].

Already before learning about Nottale's paper I had proposed the possibility that Planck constant is quantized [E9] and the spectrum is given in terms of logarithms of Beraha numbers: the lowest Beraha number  $B_3$  is completely exceptional in that it predicts infinite value of Planck constant. The inverse of the gravitational Planck constant could correspond a gravitational perturbation of this as  $1/\hbar_{gr} = v_0/GMm$ . The general philosophy would be that when the quantum system would become non-perturbative, a phase transition increasing the value of  $\hbar$  occurs to preserve the perturbative character and at the transition  $n = 4 \rightarrow 3$  only the small perturbative correction to  $1/\hbar(3) = 0$  remains. This would apply to QCD and to atoms with  $Z > 137$  as well.

TGD predicts correctly the value of the parameter  $v_0$  assuming that cosmic strings and their decay remnants are responsible for the dark matter. The harmonics of  $v_0$  can be understood as corresponding to perturbations replacing cosmic strings with their n-branched coverings so that tension becomes  $n^2$ -fold: much like the replacement of a closed orbit with an orbit closing only after  $n$  turns.  $1/n$ -sub-harmonic would result when a magnetic flux tube split into  $n$  disjoint magnetic flux tubes. Also a model for the formation of planetary system as a condensation of ordinary matter around quantum coherent dark matter emerges [D6].

### 3.5.2 Dark matter as a source of long ranged weak and color fields

Long ranged classical electro-weak and color gauge fields are unavoidable in TGD framework. The smallness of the parity breaking effects in hadronic, nuclear, and atomic length scales does not however seem to allow long ranged electro-weak gauge fields. The problem disappears if long range classical electro-weak gauge fields are identified as space-time correlates for massless gauge fields created by dark matter. Also scaled up variants of ordinary electro-weak particle spectra are possible. The identification explains chiral selection in living matter and unbroken  $U(2)_{ew}$  invariance and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

### 3.5.3 p-Adic and dark matter hierarchies and hierarchy of moments of consciousness

Dark matter hierarchy assigned to a spectrum of Planck constant having arbitrarily large values brings additional elements to the TGD inspired theory of consciousness.

a) Macroscopic quantum coherence can be understood since a particle with a given mass can in principle appear as arbitrarily large scaled up copies (Compton length scales as  $\hbar$ ). The phase transition to this kind of phase implies that space-time sheets of particles overlap and this makes possible macroscopic quantum coherence.

b) The space-time sheets with large Planck constant can be in thermal equilibrium with ordinary ones without the loss of quantum coherence. For instance, the cyclotron energy scale associated with EEG turns out to be above thermal energy at room temperature for the level of dark matter hierarchy corresponding to magnetic flux quanta of the Earth's magnetic field with the size scale of Earth and a successful quantitative model for EEG results [M3].

Dark matter hierarchy leads to detailed quantitative view about quantum biology with several testable predictions [M3]. The applications to living matter suggests that the basic hierarchy corresponds to a hierarchy of Planck constants coming as  $\hbar(k) = \lambda^k(p)\hbar_0$ ,  $\lambda \simeq 2^{11}$  for  $p = 2^{127-1}$ ,  $k = 0, 1, 2, \dots$  [M3]. Also integer valued sub-harmonics and integer valued sub-harmonics of  $\lambda$  might be possible. Each p-adic length scale corresponds to this kind of hierarchy and number theoretical arguments suggest a general formula for the allowed values of Planck constant  $\lambda$  depending logarithmically on p-adic prime [C6]. Also the value of  $\hbar_0$  has spectrum characterized by Beraha numbers  $B_n = 4\cos^2(\pi/n)$ ,  $n \geq 3$ , varying by a factor in the range  $n > 3$  [C6]. It must be however emphasized that the relation of this picture to the model of quantized gravitational Planck constant  $\hbar_{gr}$  appearing in Nottale's model is not yet completely understood.

The general prediction is that Universe is a kind of inverted Mandelbrot fractal for which each bird's eye of view reveals new structures in long length and time scales representing scaled down copies of standard physics and their dark variants. These structures would correspond to higher levels in self hierarchy. This prediction is consistent with the belief that 75 per cent of matter in the universe is dark.

#### 1. *Living matter and dark matter*

Living matter as ordinary matter quantum controlled by the dark matter hierarchy has turned out to be a particularly successful idea. The hypothesis has led to models for EEG predicting correctly the band structure and even individual resonance bands and also generalizing the notion of EEG [M3]. Also a generalization of the notion of genetic code emerges resolving the paradoxes related to the standard dogma [L2, M3]. A particularly fascinating implication is the possibility to identify great leaps in evolution as phase transitions in which new higher level of dark matter emerges [M3].

It seems safe to conclude that the dark matter hierarchy with levels labelled by the values of Planck constants explains the macroscopic and macro-temporal quantum coherence naturally.

That this explanation is consistent with the explanation based on spin glass degeneracy is suggested by following observations. First, the argument supporting spin glass degeneracy as an explanation of the macro-temporal quantum coherence does not involve the value of  $\hbar$  at all. Secondly, the failure of the perturbation theory assumed to lead to the increase of Planck constant and formation of macroscopic quantum phases could be precisely due to the emergence of a large number of new degrees of freedom due to spin glass degeneracy. Thirdly, the phase transition increasing Planck constant has concrete topological interpretation in terms of many-sheeted space-time consistent with the spin glass degeneracy.

### *2. Dark matter hierarchy and the notion of self*

The vision about dark matter hierarchy leads to a more refined view about self hierarchy and hierarchy of moments of consciousness [J6, M3]. The larger the value of Planck constant, the longer the subjectively experienced duration and the average geometric duration  $T(k) \propto \lambda^k$  of the quantum jump.

Quantum jumps form also a hierarchy with respect to p-adic and dark hierarchies and the geometric durations of quantum jumps scale like  $\hbar$ . Dark matter hierarchy suggests also a slight modification of the notion of self. Each self involves a hierarchy of dark matter levels, and one is led to ask whether the highest level in this hierarchy corresponds to single quantum jump rather than a sequence of quantum jumps. The averaging of conscious experience over quantum jumps would occur only for sub-selves at lower levels of dark matter hierarchy and these mental images would be ordered, and single moment of consciousness would be experienced as a history of events. The quantum parallel dissipation at the lower levels would give rise to the experience of flow of time. For instance, hadron as a macro-temporal quantum system in the characteristic time scale of hadron is a dissipating system at quark and gluon level corresponding to shorter p-adic time scales. One can ask whether even entire life cycle could be regarded as a single quantum jump at the highest level so that consciousness would not be completely lost even during deep sleep. This would allow to understand why we seem to know directly that this biological body of mine existed yesterday.

The fact that we can remember phone numbers with 5 to 9 digits supports the view that self corresponds at the highest dark matter level to single moment of consciousness. Self would experience the average over the sequence of moments of consciousness associated with each sub-self but there would be no averaging over the separate mental images of this kind, be their parallel or serial. These mental images correspond to sub-selves having shorter wake-up periods than self and would be experienced as being time ordered. Hence the digits in the phone number are experienced as separate mental images and ordered with respect to experienced time.

### *3. The time span of long term memories as signature for the level of dark matter hierarchy*

The simplest dimensional estimate gives for the average increment  $\tau$  of geometric time in quantum jump  $\tau \sim 10^4 CP_2$  times so that  $2^{127} - 1 \sim 10^{38}$  quantum jumps are experienced during secondary p-adic time scale  $T_2(k = 127) \simeq 0.1$  seconds which is the duration of physiological moment and predicted to be fundamental time scale of human consciousness [L1]. A more refined guess is that  $\tau_p = \sqrt{p}\tau$  gives the dependence of the duration of quantum jump on p-adic prime  $p$ . By multi-p-fractality predicted by TGD and explaining p-adic length scale hypothesis, one expects that at least  $p = 2$ -adic level is also always present. For the higher levels of dark matter hierarchy  $\tau_p$  is scaled up by  $\hbar/\hbar_0$ . One can understand evolutionary leaps as the emergence of higher levels at the level of individual organism making possible intentionality and memory in the time scale defined  $\tau$  [L2].

Higher levels of dark matter hierarchy provide a neat quantitative view about self hierarchy and its evolution. For instance, EEG time scales corresponds to  $k = 4$  level of hierarchy and a time scale of .1 seconds [J6], and EEG frequencies correspond at this level dark photon energies

above the thermal threshold so that thermal noise is not a problem anymore. Various levels of dark matter hierarchy would naturally correspond to higher levels in the hierarchy of consciousness and the typical duration of life cycle would give an idea about the level in question.

The level would determine also the time span of long term memories as discussed in [M3].  $k = 7$  would correspond to a duration of moment of conscious of order human lifetime which suggests that  $k = 7$  corresponds to the highest dark matter level relevant to our consciousness whereas higher levels would in general correspond to transpersonal consciousness.  $k = 5$  would correspond to time scale of short term memories measured in minutes and  $k = 6$  to a time scale of memories measured in days.

The emergence of these levels must have meant evolutionary leap since long term memory is also accompanied by ability to anticipate future in the same time scale. This picture would suggest that the basic difference between us and our cousins is not at the level of genome as it is usually understood but at the level of the hierarchy of magnetic bodies [L2, M3]. In fact, higher levels of dark matter hierarchy motivate the introduction of the notions of super-genome and hyper-genome. The genomes of entire organ can join to form super-genome expressing genes coherently. Hyper-genomes would result from the fusion of genomes of different organisms and collective levels of consciousness would express themselves via hyper-genome and make possible social rules and moral.

## 4 Bird's eye of view about the topics of the book

This book is devoted to what might be called classical TGD. In well-defined sense classical TGD defined as the dynamics of space-time surface determining them as kind of generalized Bohr orbits can be regarded as an exact part of quantum theory and assuming quantum classical correspondence has served as an extremely valuable guideline in the attempts to interpret TGD, to form a view about what TGD really predicts, and to guess what the underlying quantum theory could be and how it deviates from standard quantum theory. For this reason it is perhaps in order to represent the implications of the quantum classical correspondence in more detail.

### 4.0.4 The implications deriving from the topology of space-time surface and from the properties of induced gauge fields

The notions of many-sheeted space-time, topological field quantization and the notion of field/magnetic body, follow from simple topological considerations. The observation that space-time sheets can have arbitrarily large sizes and their interpretation as quantum coherence regions forces to conclude that in TGD Universe macroscopic and macro-temporal quantum coherence are possible in arbitrarily long scales. It took relatively long time to realize that perhaps the only manner to understand this is a generalization of the quantum theory itself by allowing Planck constant to be dynamical and quantized. TGD leads indeed to a "prediction" for the spectrum of Planck constants and macroscopic quantum phases with large value of Planck constant allow an identification as a dark matter hierarchy.

Also long ranged classical color and electro-weak fields are an unavoidable prediction and it took a considerable time to make the obvious conclusion: TGD Universe is fractal containing fractal copies of standard model physics at various space-time sheets and labelled by the collection of p-adic primes assignable to elementary particles and by the level of dark matter hierarchy defines as  $\hbar = \lambda^k \hbar_0$ ,  $k_d = 0, 1, \dots$ .  $\lambda$  depends logarithmically on p-adic length scale  $L(k)$  and satisfies  $\lambda \simeq 2^{11}$  in atomic length scale  $L(k = 137)$ . Dark space-time sheets are identifiable as space-time sheets defining locally  $\lambda^k$ -fold covering of  $M^4$  factor of imbedding space.

The new view about energy and time means that the sign of inertial energy depends on the time orientation of the space-time sheet and that negative energy space-time sheets serve as corre-

lates for communications to the geometric past. This alone leads to profoundly new views about metabolism, long term memory, and realization of intentional action.

A further important fact is that the holonomy group of induced color gauge field is Abelian. Together with quantum classical correspondences this suggests a weak form of color confinement in the sense that only color neutral states of color multiplets are realized as physical states.

#### **4.0.5 Vacuum degeneracy of Kähler action as a correlate for quantum criticality and 4-dimensional spin glass degeneracy**

The general properties of Kähler action, in particular its vacuum degeneracy and failure of the classical determinism in the conventional sense, have also very strong and general implications. Space-time surfaces as a generalization of Bohr orbit provide not only a representation of quantum states but also sequences of quantum jumps and thus contents of consciousness. Vacuum degeneracy implies spin glass degeneracy in 4-D sense reflecting quantum criticality which is the fundamental characteristic of TGD Universe.

#### **4.0.6 The simplest extremals of Kähler action as correlates for asymptotic self organization patterns**

The detailed study of the simplest extremals of Kähler action interpreted as correlates for asymptotic self organization patterns provides additional insights [D1].  $CP_2$  type extremals representing elementary particles, cosmic strings, vacuum extremals, topological light rays ("massless extremal", ME), flux quanta of magnetic and electric fields represent the basic extremals. Pairs of wormhole throats identifiable as parton pairs define a completely new kind of particle carrying only color quantum numbers in ideal case and I have proposed their interpretation as quantum correlates for Boolean cognition. MEs and flux quanta of magnetic and electric fields are of special importance in living matter.

This general picture serves as a cornerstone of also TGD inspired view about cosmology and astrophysics. For obvious reasons the newest ideas developed during last year and still developing (in particular, the vision about dark matter) are not discussed in full depth yet.

### **4.1 Many-sheeted cosmology**

The many-sheeted space-time concept, the new view about the relationship between inertial and gravitational four-momenta, the basic properties of the paired cosmic strings, the existence of the limiting temperature, the assumption about the existence of the vapor phase dominated by cosmic strings, and quantum criticality imply a rather detailed picture of the cosmic evolution, which differs from that provided by the standard cosmology in several respects but has also strong resemblances with inflationary scenario.

#### **4.1.1 Basic deviations from standard cosmology**

The most important differences between TGD based and standard cosmology are following.

1. Many-sheetedness implies cosmologies inside cosmologies Russian doll like structure with a spectrum of Hubble constants.
2. TGD cosmology is also genuinely quantal: each quantum jump in principle recreates each sub-cosmology in 4-dimensional sense: this makes possible a genuine evolution in cosmological length scales so that the use of anthropic principle to explain why fundamental constants are tuned for life is not necessary.

3. The new view about energy means that inertial energy is negative for space-time sheets with negative time orientation and that the density of inertial energy vanishes in cosmological length scales. Therefore any cosmology is in principle creatable from vacuum and the problem of initial values of cosmology disappears. The density of matter near the initial moment is dominated by cosmic strings approaches to zero so that big bang is transformed to a silent whisper amplified to a relatively big bang.
4. Dark matter hierarchy with dynamical quantized Planck constant implies the presence of dark space-time sheets which differ from non-dark ones in that they define multiple coverings of  $M^4$ . Quantum coherence of dark matter in the length scale of space-time sheet involved implies that even in cosmological length scales Universe is more like a living organism than a thermal soup of particles.
5. Sub-critical and over-critical Robertson-Walker cosmologies are fixed completely from the imbeddability requirement apart from a single parameter characterizing the duration of the period after which transition to sub-critical cosmology necessarily occurs. The fluctuations of the microwave background reflect the quantum criticality of the critical period rather than amplification of primordial fluctuations by exponential expansion. This and also the finite size of the space-time sheets predicts deviations from the standard cosmology.

#### 4.1.2 Cosmic strings

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

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

## 4.2 Dark matter and quantization of gravitational Planck constant

The notion of gravitational Planck constant having gigantic value is perhaps the most radical idea related to the astrophysical applications of TGD. D. Da Rocha and Laurent Nottale have proposed that Schrödinger equation with Planck constant  $\hbar$  replaced with what might be called gravitational Planck constant  $\hbar_{gr} = \frac{GmM}{v_0}$  ( $\hbar = c = 1$ ).  $v_0$  is a velocity parameter having the value  $v_0 = 144.7 \pm .7$  km/s giving  $v_0/c = 4.6 \times 10^{-4}$ . This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of  $v_0$  seem to appear. The support for the hypothesis coming from empirical data is impressive.

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

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

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

## 5 The contents of the book

In the first part of the book extremals of Kähler action are discussed and the notions of many-sheeted space-time and topological condensation and evaporation are introduced. In the second part many-sheeted-cosmology and astrophysics are summarized. The third part of the book includes some old chapters about possible implications of TGD for condensed matter physics written for at least about 15 years ago at least and updated only slightly. There is a lot of material about applications of classical TGD in its recent form to say living matter but its inclusion would have led to an explosion: this material can from seven online books about TGD [1, 2, 4, 5, 3, 6, 7] and eight online books about TGD inspired theory of consciousness and quantum biology [10, 8, 9, 13, 11, 12, 14, 15] are warmly recommended for the reader willing to get overall view about what is involved.

### 5.1 PART I: The notion of many-sheeted space-time

#### 5.1.1 Basic extremals of the Kähler action

In this chapter the classical field equations associated with the Kähler action are studied. The study of the extremals of the Kähler action has turned out to be extremely useful for the development of TGD. Towards the end of year 2003 quite dramatic progress occurred in the understanding of field equations and it seems that field equations might be in well-defined sense exactly solvable.

##### 1. General considerations

The vanishing of Lorentz 4-force for the induced Kähler field means that the vacuum 4-currents are in a mechanical equilibrium. Lorentz 4-force vanishes for all known solutions of field equations which inspires the hypothesis that all extremals or at least the absolute minima of Kähler action satisfy the condition. The vanishing of the Lorentz 4-force in turn implies local conservation of the

ordinary energy momentum tensor. The corresponding condition is implied by Einstein's equations in General Relativity. The hypothesis would mean that the solutions of field equations are what might be called generalized Beltrami fields. The condition implies that vacuum currents can be non-vanishing only provided the dimension  $D_{CP_2}$  of the  $CP_2$  projection of the space-time surface is less than four so that in the regions with  $D_{CP_2} = 4$ , Maxwell's vacuum equations are satisfied.

The hypothesis that Kähler current is proportional to a product of an arbitrary function  $\psi$  of  $CP_2$  coordinates and of the instanton current generalizes Beltrami condition and reduces to it when electric field vanishes. Kähler current has vanishing divergence for  $D_{CP_2} < 4$ , and Lorentz 4-force indeed vanishes. The remaining task would be the explicit construction of the imbeddings of these fields and the demonstration that field equations can be satisfied.

Under additional conditions magnetic field reduces to what is known as Beltrami field. Beltrami fields are known to be extremely complex but highly organized structures. The natural conjecture is that topologically quantized many-sheeted magnetic and  $Z^0$  magnetic Beltrami fields and their generalizations serve as templates for the helical molecules populating living matter, and explain both chirality selection, the complex linking and knotting of DNA and protein molecules, and even the extremely complex and self-organized dynamics of biological systems at the molecular level.

Field equations can be reduced to algebraic conditions stating that energy momentum tensor and second fundamental form have no common components (this occurs also for minimal surfaces in string models) and only the conditions stating that Kähler current vanishes, is light-like, or proportional to instanton current, remain and define the remaining field equations. The conditions guaranteeing topologization to instanton current can be solved explicitly. Solutions can be found also in the more general case when Kähler current is not proportional to instanton current. On basis of these findings there are strong reasons to believe that classical TGD is exactly solvable.

### *2. Does TGD define a generalized topological quantum field theory?*

A long standing assumption has been that the principle selecting the unique space-time going through given 3-surface (not reducing to single space-like component however) is absolute minimization of Kähler action. The number theoretical considerations suggest a more refined and more local principle, in which maximization or minimization of the value occurs for regions where the sign of action density is definite [E2] and that these two variational principles define dual pairs of 4-surfaces. This variational principle allows to interpret space-time surfaces generalized calibrations for which Kähler action density defines a four-form worm the physical extremals so that theory can be said to be topologized.

In fact already the generalized Bohr orbit property leads one to suspect that classical TGD defines a topological field theory generalized in such a manner that various conserved Noether charges can be regarded as topological invariants as extrema of these invariants for a given topology of 3-surface. There are of course zero modes characterizing the shape and size of the four-surface involved. Perhaps the maxima of Kähler function with respect to the zero modes define genuine topological invariants.

### *3. Generalized Bohr orbit property and second law of thermodynamics?*

By quantum classical correspondence the non-deterministic space-time dynamics should mimic the dissipative dynamics of the quantum jump sequence. Beltrami fields appear in physical applications as asymptotic self organization patterns for which Lorentz force and dissipation vanish. This suggests that the preferred extrema defining the Bohr orbits, be they absolute minima of Kähler action or something more general, correspond to space-time sheets which asymptotically satisfy generalized Beltrami conditions so that one can indeed assign to the final (rather than initial!) 3-surface a unique 4-surface apart from effects related to non-determinism. Absolute minimization makes sense p-adically only if abstracted to purely algebraic generalized Beltrami conditions. The notion of Kähler calibration is purely algebraic local notion and certainly makes

sense also p-adically. Also the equivalence of Bohr orbit property with the second law strongly suggests itself.

#### 4. The dimension of $CP_2$ projection as classifier for the fundamental phases of matter

The dimension  $D_{CP_2}$  of  $CP_2$  projection of the space-time sheet encountered already in p-adic mass calculations classifies the fundamental phases of matter. For  $D_{CP_2} = 4$  empty space Maxwell equations hold true. This phase is chaotic and analogous to de-magnetized phase.  $D_{CP_2} = 2$  phase is analogous to ferromagnetic phase: highly ordered and relatively simple.  $D_{CP_2} = 3$  is the analog of spin glass and liquid crystal phases, extremely complex but highly organized by the properties of the generalized Beltrami fields. This phase is the boundary between chaos and order and corresponds to life emerging in the interaction of magnetic bodies with bio-matter. It is possible only in a finite temperature interval (note however the p-adic hierarchy of critical temperatures) and characterized by chirality just like life.

#### 5. Specific extremals of Kähler action

The study of extremals of Kähler action represents more than decade old layer in the development of TGD.

1. The huge vacuum degeneracy is the most characteristic feature of Kähler action (any 4-surface having  $CP_2$  projection which is Legendre sub-manifold is vacuum extremal, Legendre sub-manifolds of  $CP_2$  are in general 2-dimensional). This vacuum degeneracy is behind the spin glass analogy and leads to the p-adic TGD. As found in the second part of the book, various particle like vacuum extremals also play an important role in the understanding of the quantum TGD.
2. The so called  $CP_2$  type vacuum extremals have finite, negative action and are therefore an excellent candidate for real particles whereas vacuum extremals with vanishing Kähler action are candidates for the virtual particles. These extremals have one dimensional  $M^4$  projection, which is light like curve but not necessarily geodesic and locally the metric of the extremal is that of  $CP_2$ : the quantization of this motion leads to Virasoro algebra. Space-times with topology  $CP_2 \# CP_2 \# \dots CP_2$  are identified as the generalized Feynmann diagrams with lines thickened to 4-manifolds of "thickness" of the order of  $CP_2$  radius. The quantization of the random motion with light velocity associated with the  $CP_2$  type extremals in fact led to the discovery of Super Virasoro invariance, which through the construction of the configuration space geometry, becomes a basic symmetry of quantum TGD.
3. There are also various non-vacuum extremals.
  - i) String like objects, with string tension of same order of magnitude as possessed by the cosmic strings of GUTs, have a crucial role in TGD inspired model for the galaxy formation and in the TGD based cosmology.
  - ii) The so called massless extremals describe non-linear plane waves propagating with the velocity of light such that the polarization is fixed in given point of the space-time surface. The purely TGD:ish feature is the light like Kähler current: in the ordinary Maxwell theory vacuum gauge currents are not possible. This current serves as a source of coherent photons, which might play an important role in the quantum model of bio-system as a macroscopic quantum system.
  - iii) In the so called Maxwell's phase, ordinary Maxwell equations for the induced Kähler field are satisfied in an excellent approximation. A special case is provided by a radially symmetric extremal having an interpretation as the space-time exterior to a topologically condensed particle. The sign of the gravitational mass correlates with that of the Kähler charge and one can understand the generation of the matter antimatter asymmetry from the basic properties of this extremal. The possibility to understand the generation of the matter

antimatter asymmetry directly from the basic equations of the theory gives strong support in favor of TGD in comparison to the ordinary EYM theories, where the generation of the matter antimatter asymmetry is still poorly understood.

### 5.1.2 General View About Physics in Many-Sheeted Space-Time: Part I

In this chapter the notion of many-sheeted space-time is discussed. Topological condensation and evaporation represent the basic new concepts of TGD and an attempt to formulate a general qualitative theory of the topological condensation and evaporation and TGD based space-time concept is made.

The notion of many-sheeted space-time used is roughly that as it was around 1990. The fusion of real and various p-adic physics to single coherent whole by generalizing the notion of number, the generalization of the notion of the imbedding space to allow a mathematical representation of dark matter hierarchy based on dynamical and quantized Planck constant, parton level formulation of TGD using light-like 3-surfaces as basic dynamical objects, and so called zero energy ontology force to generalizes considerably the view about space-time. These developments are discussed in the next chapter.

The topics to be discussed in the sequel will be following.

#### 1. *The general structure of topological condensate*

The question what 3-space looks like in various scales and end up to a purely topological description for the generation of structures. Topological arguments imply a finite size for non-vacuum 3-surfaces and the conservation of the gauge and gravitational fluxes requires that 3-surface feeds these fluxes to a larger 3-surface via # contacts situated near the boundaries of the 3-surface. Renormalization group invariance (RGI) hypothesis suggests that 3-surfaces with all sizes are important in the functional integral and this leads to the idea of the many-sheeted space-time with hierarchical, fractal like structure such that each level of the hierarchy corresponds to a characteristic length scale.

#### 2. *Topological field quantization*

The general space-time picture suggested by RGI hypothesis can be justified mathematically. Due to the compactness of  $CP_2$ , a general space-time surface representable as a map  $M^4 \rightarrow CP_2$  decomposes into regions, "topological field quanta", characterized by certain vacuum quantum numbers and 3-surface is in general unstable against the decay to disjoint components along the boundaries of the field quanta.

Topological field quanta have finite size depending on the values of the vacuum quantum numbers: the size increases as the values of the vacuum quantum numbers increase. Topological field quantum is therefore a good candidate for a quantum coherent system provided some Bose Einstein condensate or quantum coherent state is available. The BE condensate or coherent state of the light # contacts near the boundaries of the topological field quantum is a good candidate in this respect. It came as a total surprise that this the generation of vacuum expectation value of Higgs field corresponds to the generation of this kind of macroscopic quantum phase.

The requirement of the gauge charge conservation in turn implies the hierarchical structure of the topological condensate: gauge fluxes must go somewhere from the outer boundaries of the topological field quantum with finite size and this 'somewhere' must be a larger topological field quantum, which in turn feeds its gauge fluxes to a larger topological field quantum,.... Of course, the nonlinearity of the theory could allow vacuum charge densities which can cancel the net charge near boundaries.

Most importantly, topological field quanta allow discrete scalings as a dynamical symmetry. p-Adic length scale hypothesis states that the allowed scaling factors correspond to powers of  $\sqrt[p]{p}$ , where the prime  $p$  satisfies  $p \simeq 2^k$ ,  $k$  integer with prime values favored. p-Adic fractality (actually

multi-p-fractality) can be justified more rigorously by a precise formulation for the fusion of real and various p-adic physics based on the generalization of the notion of number.

### 3. General physical consequences of new view about space-time

The physical consequences of the new space-time picture are nontrivial at all length scales.

1. A natural interpretation for the hierarchical structure is in terms of bound state formation. Quarks condense to form hadrons, nucleons condense to form atomic nuclei, nuclei and electrons condense to form atoms, how atoms condense to form molecules, and so on. One ends up with a general picture for the topology of 3-space associated with, say, solid state and with the idea that even the macroscopic bodies of the everyday world correspond to topologically condensed 3-surfaces.
2. The join of 3-surfaces along their boundaries defines a new kind of interaction, which has in fact has been used in phenomenological modelling of chemical reactions. Usually chemical bond is believed to result from Schrödinger equation. At the macroscopic level this interaction is rather familiar to us since it means that two macroscopic bodies just touch each other.
3. In TGD context there are purely topological necessary conditions for quantum coherence and a topological description for dissipative phenomena. The formation of the join along boundaries bonds plays a decisive role in the description and this process provides a universal manner to generate macroscopic quantum systems. There is also a topological description for the formation of the supra phases and the phase of the order parameter of the supra phase ground state contains information about the homotopy of the join along boundaries condensate.

### 4. Gauge bosons and Higgs boson as wormhole contacts, electro-weak symmetry breaking, the weakening of Equivalence Principle, and color confinement

The proper understanding of the concepts of gauge charges and fluxes and their gravitational counterparts in TGD space-time has taken a lot of efforts. At the fundamental level gauge charges assignable to light-like 3-D elementary particle horizons surrounding a topologically condensed  $CP_2$  type extremals can be identified as the quantum numbers assignable to fermionic oscillator operators generating the state associated with horizon identifiable as a parton. Quantum classical correspondence requires that commuting classical gauge charges are quantized and this is expected to be true by the generalized Bohr orbit property of the space-time surface.

There are however non-trivial questions. Do vacuum charge densities give rise to renormalization effects or imply non-conservation so that weak charges would be screened above intermediate boson length scale? Could one assign the non-conservation of gauge fluxes to the wormhole (#) contacts, which are identifiable as pieces of  $CP_2$  extremals and for which electro-weak gauge currents are not conserved so that weak gauge fluxes would be non-vanishing but more or less random so that long range correlations would be lost?

It indeed turns that one can understand the non-conservation of weak gauge fluxes in terms of wormhole contacts carrying pairs of right/left handed fermion and left/right handed antifermion having interpretation as Higgs bosons. The average non-conserved light-like gravitational four-momentum of wormhole contact representing Higgs boson can be identified as the inertial four-momentum apart from the sign factor so that one can also understand particle massivation at fundamental level and a connection with p-adic thermodynamics based description of Higgs mechanism emerges. Also a detailed understanding about how Equivalence Principle is weakened in TGD framework emerges.

Later it became clear that all gauge bosons must be identified as wormhole contacts whereas elementary fermions correspond to wormhole throats associated with topologically condensed  $CP_2$  type vacuum extremals.

Also color confinement can be understood using only quantum classical correspondence and general properties of classical color gauge field. Spin glass degeneracy allows to understand the generation of macro-temporal quantum coherence and the same mechanism allows also to understand more quantitatively color confinement by applying unitarity conditions.

#### 5. Wormhole contacts, super-conductivity, and biology

Wormhole contacts, feeding gauge fluxes from a given sheet of the 3-space to a larger one, which are a necessary concomitant of the many-sheeted space-time concept. # contacts can be regarded as particles carrying classical charges defined by the gauge fluxes but behaving as extremely tiny dipoles quantum mechanically in the case that gauge charge is conserved. # contacts must be light, which suggests that they can form Bose-Einstein condensates and coherent states. The real surprise (after 27 years of TGD) was that the formation of these rather exotic macroscopic quantum phases could be identified as formation of vacuum expectation value of Higgs field for various scaled up copies of standard model physics. This kind of macroscopic quantum phases could be in a central role in the TGD inspired model for a bio-system as a macroscopic quantum system. Electromagnetically charged # contacts are also possible and would explain the massivation of photons in super-conductors implying that long ranged exotic  $W$  boson exchanges play a key role in super-conductivity.

#### 6. The interpretation of long range weak and color gauge fields

In TGD gravitational fields are accompanied by long ranged electro-weak and color gauge fields. The only possible interpretation is that there exists a p-adic hierarchy of color and electro-weak physics such that weak bosons are massless below the p-adic length scale determining the mass scale of weak bosons. By quantum classical correspondence classical long ranged gauge fields serve as space-time correlates for gauge bosons below the p-adic length scale in question.

The unavoidable long ranged electro-weak and color gauge fields are created by dark matter and dark particles can screen dark nuclear electro-weak charges below the weak scale. Above this scale vacuum screening occurs as for ordinary weak interactions. Dark gauge bosons are massless below the appropriate p-adic length scale but massive above it and  $U(2)_{ew}$  is broken only in the fermionic sector. For dark copies of ordinary fermions masses are essentially identical with those of ordinary fermions.

This interpretation is consistent with the standard elementary particle physics for visible matter apart from predictions such as the possibility of p-adically scaled up versions of ordinary quarks predicted to appear already in ordinary low energy hadron physics. The most interesting implications are seen in longer length scales. Dark variants of ordinary valence quarks and gluons and a scaled up copy of ordinary quarks and gluons are predicted to emerge already in ordinary nuclear physics. Chiral selection in living matter suggests that dark matter is an essential component of living systems so that non-broken  $U(2)_{ew}$  symmetry and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

#### 7. Renormalization group equations at space-time level

Renormalization group evolution equations for gauge couplings at given space-time sheet are discussed using quantum classical correspondence. For known extremals of Kähler action gauge couplings are RG invariants inside single space-time sheet, which supports the view that discrete p-adic coupling constant evolution replaces the ordinary coupling constant evolution.

## 5.2 General View About Physics in Many-Sheeted Space-Time: Part II

In this chapter the view about many-sheeted space-time is completed by a summary of the developments in TGD that have occurred during last few years (the year I am writing this is 2007). The most important steps of progress are following ones.

### 1. Parton level formulation of quantum TGD

The formulation of quantum TGD at partonic level identifying fundamental objects as light-like 3-surfaces having also interpretation as random light-like orbits of 2-D partons having arbitrarily large size. This picture reduces quantum TGD to an almost-topological quantum field theory and leads to a dramatic understanding of S-matrix. A generalization of Feynman diagrams emerges obtained by replacing lines of Feynman diagram with light-like 3-surfaces meeting along their ends at vertices. This picture is different from that of string models and means also a generalization of the view about space-time and 3-surface since these surfaces cannot be assumed to be a smooth manifold anymore.

### 2. Zero energy ontology

In zero energy ontology physical states are creatable from vacuum and have vanishing net quantum numbers, in particular energy. Zero energy states can be decomposed to positive and negative energy parts with definite geometro-temporal separation, call it  $T$ , and having interpretation in terms of initial and final states of particle reactions. Zero energy ontology is consistent with ordinary positive energy ontology at the limit when the time scale of the perception of observer is much shorter than  $T$ .

Zero energy ontology leads to the view about S-matrix as a characterizer of time-like entanglement associated with the zero energy state and a generalization of S-matrix to what might be called M-matrix emerges. M-matrix is complex square root of density matrix expressible as a product of real valued "modulus" and unitary matrix representing phase and can be seen as a matrix valued generalization of Schrödinger amplitude. Also thermodynamics becomes an inherent element of quantum theory in this approach.

### 3. Fusion of real and p-adic physics to single one

The fusion of p-adic physics and real physics to single coherent whole requires generalization of the number concept obtained by gluing reals and various p-adic number fields along common algebraic numbers. This leads to a new vision about how cognition and intentionality make themselves visible in real physics via long range correlations realized via the effective p-adicity of real physics. The success of the p-adic length scale hypothesis and p-adic mass calculations suggest that cognition and intentionality are present already at elementary particle level. This picture leads naturally to an effective discretization of the real physics at the level of S-matrix and relying on the notion of umber theoretic braid.

### 4. Dark matter hierarchy and hierarchy of Planck constants

Dark matter revolution with levels of the hierarchy labelled by values of Planck constant forces a further generalization of the notion of imbedding space and thus of space-time. One can say, that imbedding space is a book like structure obtained by gluing together infinite number of copies of the imbedding space like pages of a book: two copies characterized by singular discrete bundle structure are glued together along 4-dimensional set of common points. These points have physical interpretation in terms of quantum criticality. Particle states belonging to different sectors (pages of the book) can interact via field bodies representing space-time sheets which have parts belonging to two pages of this book.

### 5. p-Adic coupling constant evolution

Kähler coupling strength is analogous to critical temperature. The understanding the spectrum for the values of  $\alpha_K$  has been one of the basic challenges of quantum TGD. Second question has been whether Kähler coupling strength is invariant under p-adic coupling constant evolution or not. The recent view is that Kähler coupling constant is invariant in this sense and that its spectrum is very simple:  $\alpha_K = 1/4k$ , where  $k$  is the integer valued Chern-Simons coupling in the parton level formulation of quantum TGD in terms of Chern-Simons action for the induced Kähler form.

Also p-adic temperature is naturally given as  $T_p = 1/k$ . For elementary fermions and super-canonical quanta one has  $k = 1$  and for gauge bosons  $T_p = 26$  if one requires that Kähler coupling strength equals to electro-weak  $U(1)$  coupling strength at electron length scale corresponding to Mersenne prime  $M_{127}$ . The hypothesis relates also the evolution of color coupling strength to that of  $U(1)$  coupling strength.

This picture has profound consequences. For instance, gauge boson masses are in excellent approximation due to coupling to Higgs boson and fermion masses originate from p-adic thermodynamics. Also a detailed understanding of hadronic anatomy in terms of super-canonical quanta and a microscopic theory of black-holes emerge.

## 5.3 PART II: Many-Sheeted Cosmology, and Astrophysics

### 5.3.1 The Relationship Between TGD and GRT

In this chapter the recent view about TGD as Poincare invariant theory of gravitation is discussed. Radically new views about ontology were necessary before it was possible to see what had been there all the time. Zero energy ontology states that all physical states have vanishing net quantum numbers. The hierarchy of dark matter identified as macroscopic quantum phases labelled by arbitrarily large values of Planck constant is second aspect of the new ontology.

#### 1. *The fate of Equivalence Principle*

There seems to be a fundamental obstacles against the existence of a Poincare invariant theory of gravitation related to the notions of inertial and gravitational energy.

1. The conservation laws of inertial energy and momentum assigned to the fundamental action would be exact in this kind of a theory. Gravitational four-momentum can be assigned to the curvature scalar as Noether currents and is thus completely well-defined unlike in GRT. Equivalence Principle requires that inertial and gravitational four-momenta are identical. This is satisfied if curvature scalar defines the fundamental action principle crucial for the definition of quantum TGD. Curvature scalar as a fundamental action is however non-physical and had to be replaced with so called Kähler action.
2. One can question Equivalence Principle because the conservation of gravitational four-momentum seems to fail in cosmological scales.
3. For the extremals of Kähler action the Noether currents associated with curvature scalar are well-defined but non-conserved. Also for vacuum extremals satisfying Einstein's equations gravitational energy momentum is not conserved and non-conservation becomes large for small values of cosmic time. This looks fine but the problem is whether the failure of Equivalence Principle is so serious that it leads to conflict with experimental facts.

It turns out that Equivalence Principle can hold true for elementary particles having so called  $CP_2$  type extremals as space-time correlates and for hadrons having string like objects as space-time correlates. This is more or less enough to have consistency with experimental facts. Equivalence Principle fails for vacuum extremals representing Robertson-Walker cosmologies and for all vacuum extremals representing solutions of Einstein's equations. The failure is very dramatic for string

like objects that I have used to call cosmic strings. These failures can be however understood in zero energy ontology.

### 2. *The problem of cosmological constant*

A further implication of dark matter hierarchy is that astrophysical systems correspond to stationary states analogous to atoms and do not participate to cosmic expansion in a continuous manner but via discrete quantum phase transitions in which gravitational Planck constant increases. By quantum criticality of these phase transitions critical cosmologies are excellent candidates for the modelling of these transitions. Imbeddable critical cosmologies are unique apart from a parameter determining their duration and represent accelerating cosmic expansion so that there is no need to introduce cosmological constant.

It indeed turns out possible to understand these critical phases in terms of quantum phase transition increasing the size of large modelled in terms of "big" cosmic strings with negative gravitational mass whose repulsive gravitation drives "galactic" cosmic strings with positive gravitational mass to the boundaries of the void. In this framework cosmological constant like parameter does not characterize the density of dark energy but that of dark matter identifiable as quantum phases with large Planck constant.

A further problem is that the naive estimate for the cosmological constant is predicted to be by a factor  $10^{120}$  larger than its value deduced from the accelerated expansion of the Universe. In TGD framework the resolution of the problem comes naturally from the fact that large voids are quantum systems which follow the cosmic expansion only during the quantum critical phases.

p-Adic fractality predicting that cosmological constant is reduced by a power of 2 in phase transitions occurring at times  $T(k) \propto 2^{k/2}$ , which correspond to p-adic time scales. These phase transitions would naturally correspond to quantum phase transitions increasing the size of the large voids during which critical cosmology predicting accelerated expansion naturally applies. On the average  $\Lambda(k)$  behaves as  $1/a^2$ , where  $a$  is the light-cone proper time. This predicts correctly the order of magnitude for observed value of  $\Lambda$ .

### 3. *Topics of the chapter*

The topics discussed in the chapter are following.

1. The relationship between TGD and GRT is discussed applying recent views about the relationship of inertial and gravitational masses, the zero energy ontology, and dark matter hierarchy. One of the basic outcomes is the TGD based understanding of cosmological constant as characterized of dark matter density.
2. The notion of many-sheeted space time interpreted as a hierarchy of smoothed out space-times produced by Nature itself rather than only renormalization group theorist is discussed. The dynamics of what might be called gravitational charges is discussed the basic idea being that the structure of Einstein's tensor automatically implies that metric carries information about sources of the gravitational field without any assumption about variational principle.
3. The theory is applied to the vacuum extremal embeddings of Reissner-Nordström and Schwarzschild metric.
4. A model for the final state of a star, which indicates that  $Z^0$  force, presumably created by dark matter, might have an important role in the dynamics of the compact objects. During year 2003, more than decade after the formulation of the model, the discovery of the connection between supernovas and gamma ray bursts provided strong support for the predicted axial magnetic and  $Z^0$  magnetic flux tube structures predicted by the model for the final state of a rotating star. Two years later the interpretation of the predicted long range weak forces as being caused by dark matter emerged.

The recent progress in understanding of hadronic mass calculations has led to the identification of so called super-canonical bosons and their super-counterparts as basic building blocks of hadrons. This notion leads also to a microscopic description of neutron stars and black-holes in terms of highly entangled string like objects in Hagedorn temperature and in very precise sense analogous to gigantic hadrons.

5. There is experimental evidence for gravimagnetic fields in rotating superconductors which are by 20 orders of magnitudes stronger than predicted by general relativity. A TGD based explanation of these observations is discussed.

### 5.3.2 Cosmic strings

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

#### 1. Basic ideas

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

1. Zero energy ontology implies that the inertial energy and all quantum numbers of the Universe vanishes and physical states are zero energy states decomposing into pairs of positive and negative energy states. Positive energy ontology is a good approximation under certain assumptions.
2. Dark matter hierarchy whose levels are labelled by gigantic values of gravitational Planck constant associated with dark matter is second essential piece of the picture.
3. The identification of gravitational four-momentum as the Noether charge associated with curvature scalar looks in retrospect completely obvious and resolves the long standing ambiguities. This identification explains the non-conservation of gravitational four-momentum which is in contrast with the conservation of inertial four-momentum and implies breaking of Equivalence Principle. There are good reasons to believe that this breaking can be avoided for elementary particles and hadronic strings.
4. The gravitational energy of string like objects  $X^2 \times Y^2 \subset M^4 \times CP_2$  corresponds to gravitational string tension  $T_{gr} = (1 - g)/4G$  which is negative for  $g > 1$ . The string tension is by a factor of order  $10^7$  larger than the inertial string tension. This leads to the hypothesis that  $g > 1$  "big" strings in the centers of large voids generate repulsive gravitational force driving  $g = 1$  galactic strings to the boundaries of the voids. If the total gravitational mass of strings inside voids vanishes, the breaking of Equivalence Principle occurs only below the size scale of the void.
5. The basic question whether one can model the exterior region of the topologically condensed cosmic string using General Relativity. The exterior metric of the cosmic string corresponds to a small deformation of a vacuum extremal. The angular defect and surplus associated with the exterior metrics extremizing curvature scalar can be much smaller than assuming vacuum Einstein's equations. The conjecture is that the exterior metric of  $g = 1$  galactic string conforms with the Newtonian intuitions and thus explains the constant velocity spectrum of distant stars if one assumes that galaxies are organized to linear structures along long strings like pearls in a necklace.

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

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

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

The sizes of large voids stay constant during stationary periods which means that also cosmological constant is piecewise constant. p-Adic length fractality predicts that  $\Lambda$  scales as  $1/L^2(k)$  as a function of the p-adic scale characterizing the space-time sheet of void. The order of magnitude for the recent value of the cosmological constant comes out correctly. The gravitational energy density described by the cosmological constant is identifiable as that associated with topologically condensed cosmic strings and of magnetic flux tubes to which they are gradually transformed during cosmological evolution.

## 3. Cosmic strings and generation of structures

1. In zero energy ontology cosmic strings must be created from vacuum as zero energy states consisting of pairs of strings with opposite time orientation and inertial energy.
2. The counterpart of Hawking radiation provides a mechanism by which cosmic strings can generate ordinary matter. The splitting of cosmic strings followed by a "burning" of the string ends provides a second manner to generate visible matter. Matter-antimatter symmetry would result if antimatter is inside cosmic strings and matter in the exterior region.
3. Zero energy ontology has deep implications for the cosmic and ultimately also for biological evolution (magnetic flux tubes play a fundamental role in TGD inspired biology and cosmic strings are limiting cases of them). The arrows of geometric time are opposite for the strings and also for positive energy matter and negative energy antimatter. This implies a competition between two dissipative time developments proceeding in different directions of geometric time and looking self-organization and even self-assembly from the point of view of each other. This resolves paradoxes created by gravitational self-organization contra second law of thermodynamics. So called super-canonical matter at cosmic strings implies large p-adic entropy resolves the well-known entropy paradox.
4. p-Adic fractality and simple quantitative observations lead to the hypothesis that cosmic strings are responsible for the evolution of astrophysical structures in a very wide length scale range. Large voids with size of order  $10^8$  light years can be seen as structures cosmic strings wound around the boundaries of the void. Galaxies correspond to same structure with smaller size and linked around the supra-galactic strings. This conforms with the finding that galaxies tend to be grouped along linear structures. Simple quantitative estimates show that even stars and planets could be seen as structures formed around cosmic strings of appropriate size. Thus Universe could be seen as fractal cosmic necklace consisting of cosmic strings linked like pearls around longer cosmic strings linked like...

#### 4. Cosmic strings, gamma ray bursts, and supernovae

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

1. A correlation between supernovae and gamma ray bursts was observed.
2. Evidence that some unknown particles of mass  $m \simeq 2m_e$  and decaying to gamma rays and/or electron positron pairs annihilating immediately serve as signatures of dark matter. These findings challenge the identification of cosmic strings and/or their decay products as dark matter, and also the idea that gamma ray bursts correspond to cosmic fire crackers formed by the decaying ends of cosmic strings. This forces the updating of the more than decade old rough vision about topologically condensed cosmic strings and about gamma ray bursts described in this chapter.

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

The flow of matter along  $Z^0$  magnetic (rotation) axis generates synchrotron radiation, which escapes as a precisely targeted beam along magnetic axis and leaves the star. The identification is as the rotating light beam associated with ordinary neutron stars. During the core collapse leading to the supernova this beam becomes gamma ray burst. The mechanism is very much analogous to the squeezing of the tooth paste from the tube. The fact that all nuclei are fully ionized  $Z^0$  ions, the  $Z^0$  charge unbalance caused by the ejection of neutrinos, and the radial compression make the effect extremely strong so that there are hopes to understand the observed incredibly high polarization of  $80 \pm 20$  per cent.

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

#### 5.3.3 TGD inspired cosmology

A proposal for what might be called TGD inspired cosmology is made. The basic ingredient of this cosmology is the TGD counter part of the cosmic string. It is found that many-sheeted space-time concept; the new view about the relationship between inertial and gravitational four-momenta; the basic properties of the cosmic strings; zero energy ontology; the hierarchy of dark matter with levels labelled by arbitrarily large values of Planck constant: the existence of the limiting temperature (as in string model, too); the assumption about the existence of the vapor phase dominated by cosmic strings; and quantum criticality imply a rather detailed picture of the cosmic evolution, which differs from that provided by the standard cosmology in several respects but has also strong resemblances with inflationary scenario.

TGD inspired cosmology in its recent form relies on an ontology differing dramatically from that of GRT based cosmologies. Zero energy ontology states that all physical states have vanishing net quantum numbers so that all matter is creatable from vacuum. The hierarchy of dark matter identified as macroscopic quantum phases labelled by arbitrarily large values of Planck constant is second aspect of the new ontology. The values of the gravitational Planck constant assignable to

space-time sheets mediating gravitational interaction are gigantic. This implies that TGD inspired late cosmology might decompose into stationary phases corresponding to stationary quantum states in cosmological scales and critical cosmologies corresponding to quantum transitions changing the value of the gravitational Planck constant and inducing an accelerated cosmic expansion.

### 1. *Zero energy ontology*

The construction of quantum theory leads naturally to zero energy ontology stating that everything is creatable from vacuum. Zero energy states decompose into positive and negative energy parts having identification as initial and final states of particle reaction in time scales of perception longer than the geometro-temporal separation  $T$  of positive and negative energy parts of the state. If the time scale of perception is smaller than  $T$ , the usual positive energy ontology applies.

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

### 2. *Dark matter hierarchy and hierarchy of Planck constants*

Dark matter revolution with levels of the hierarchy labelled by values of Planck constant forces a further generalization of the notion of imbedding space and thus of space-time. One can say, that imbedding space is a book like structure obtained by gluing together infinite number of copies of the imbedding space like pages of a book: two copies characterized by singular discrete bundle structure are glued together along 4-dimensional set of common points. These points have physical interpretation in terms of quantum criticality. Particle states belonging to different sectors (pages of the book) can interact via field bodies representing space-time sheets which have parts belonging to two pages of this book.

### 3. *Quantum criticality*

TGD Universe is quantum counterpart of a statistical system at critical temperature. As a consequence, topological condensate is expected to possess hierarchical, fractal like structure containing topologically condensed 3-surfaces with all possible sizes. Both Kähler magnetized and Kähler electric 3-surfaces ought to be important and string like objects indeed provide a good example of Kähler magnetic structures important in TGD inspired cosmology. In particular space-time is expected to be many-sheeted even at cosmological scales and ordinary cosmology must be replaced with many-sheeted cosmology. The presence of vapor phase consisting of free cosmic strings and possibly also elementary particles is second crucial aspects of TGD inspired cosmology.

Quantum criticality of TGD Universe supports the view that many-sheeted cosmology is in some sense critical. Criticality in turn suggests fractality. Phase transitions, in particular the topological phase transitions giving rise to new space-time sheets, are (quantum) critical phenomena involving no scales. If the curvature of the 3-space does not vanish, it defines scale: hence the flatness of the cosmic time=constant section of the cosmology implied by the criticality is consistent with the scale invariance of the critical phenomena. This motivates the assumption that the new space-time sheets created in topological phase transitions are in good approximation modellable as critical Robertson-Walker cosmologies for some period of time at least.

These phase transitions are between stationary quantum states having stationary cosmologies as space-time correlates: also these cosmologies are determined uniquely apart from single parameter.

### 4. *Only sub-critical cosmologies are globally imbeddable*

TGD allows global imbedding of subcritical cosmologies. A partial imbedding of one-parameter

families of critical and overcritical cosmologies is possible. The infinite size of the horizon for the imbeddable critical cosmologies is in accordance with the presence of arbitrarily long range fluctuations at criticality and guarantees the average isotropy of the cosmology. Imbedding is possible for some critical duration of time. The parameter labelling these cosmologies is scale factor characterizing the duration of the critical period. These cosmologies have the same optical properties as inflationary cosmologies. Critical cosmology can be regarded as a 'Silent Whisper amplified to Bang' rather than 'Big Bang' and transformed to hyperbolic cosmology before its imbedding fails. Split strings decay to elementary particles in this transition and give rise to seeds of galaxies. In some later stage the hyperbolic cosmology can decompose to disjoint 3-surfaces. Thus each sub-cosmology is analogous to biological growth process leading eventually to death.

#### 5. *Fractal many-sheeted cosmology*

The critical cosmologies can be used as a building blocks of a fractal cosmology containing cosmologies containing ... cosmologies. p-Adic length scale hypothesis allows a quantitative formulation of the fractality. Fractal cosmology predicts cosmos to have essentially same optic properties as inflationary scenario but avoids the prediction of unknown vacuum energy density. Fractal cosmology explains the paradoxical result that the observed density of the matter is much lower than the critical density associated with the largest space-time sheet of the fractal cosmology. Also the observation that some astrophysical objects seem to be older than the Universe, finds a nice explanation.

#### 6. *Equivalence Principle in TGD framework*

The failure of Equivalence Principle in TGD Universe was something which was very difficult to take seriously and this led to a long series of ad hoc constructs trying to save Equivalence Principle instead of trying to characterize the failure, to find out whether it has catastrophic consequences, and to relate it to the recent problems of cosmology, in particular the necessity to postulate somewhat mysterious dark energy characterized by cosmological constant. The irony was that all this was possible since TGD allows to define both inertial and gravitational four-momenta and generalized gravitational charges assignable to isometries of  $M^4 \times CP_2$  precisely.

It indeed turns out that Equivalence Principle can hold true for elementary particles having so called  $CP_2$  type extremals as space-time correlates and for hadrons having string like objects as space-time correlates. This is more or less enough to have consistency with experimental facts. Equivalence Principle fails for vacuum extremals representing Robertson-Walker cosmologies and for all vacuum extremals representing solutions of Einstein's equations. The failure is very dramatic for string like objects that I have used to call cosmic strings. These failures can be however understood in zero energy ontology.

#### 7. *Cosmic strings as basic building blocks of TGD inspired cosmology*

Cosmic strings are the basic building blocks of TGD inspired cosmology and all structures including large voids, galaxies, stars, and even planets can be seen as pearls in a cosmic fractal necklaces consisting of cosmic strings containing smaller cosmic strings linked around them containing... During cosmological evolution the cosmic strings are transformed to magnetic flux tubes with smaller Kähler string tension and these structures are also key players in TGD inspired quantum biology.

Cosmic strings are of form  $X^2 \times Y^2 \subset M^4 \times CP_2$ , where  $X^2$  corresponds to string orbit and  $Y^2$  is a complex sub-manifold of  $CP_2$ . The gravitational mass of cosmic string is  $M_{gr} = (1-g)/4G$ , where  $g$  is the genus of  $Y^2$ . For  $g = 1$  the mass vanishes. When  $Y^2$  corresponds to homologically trivial geodesic sphere of  $CP_2$  the presence of Kähler magnetic field is however expected to generate inertial mass which also gives rise to gravitational mass visible as asymptotic behavior of the metric of space-time sheet at which the cosmic string has suffered topological condensation. The

corresponding string tension is in the same range that for GUT strings and explains the constant velocity spectrum of distant stars around galaxies.

For  $g > 1$  the gravitational mass is negative. This inspires a model for large voids as space-time regions containing  $g > 1$  cosmic string with negative gravitational energy and repelling the galactic  $g = 0$  cosmic strings to the boundaries of the large void.

These voids would participate cosmic expansion only in average sense. During stationary periods the quantum states would be modellable using stationary cosmologies and during phase transitions increasing gravitational Planck constant and thus size of the large void they critical cosmologies would be the appropriate description. The acceleration of cosmic expansion predicted by critical cosmologies can be naturally assigned with these periods. Classically the quantum phase transition would be induced when galactic strings are driven to the boundary of the large void by the antigravity of big cosmic strings with negative gravitational energy. The large values of Planck constant are crucial for understanding of living matter so that gravitation would play fundamental role also in the evolution of life and intelligence.

Many-sheeted fractal cosmology containing both hyperbolic and critical space-time sheets based on cosmic strings suggests an explanation for several puzzles of GRT based cosmology such as dark matter problem, origin of matter antimatter asymmetry, the problem of cosmological constant and mechanism of accelerated expansion, the problem of several Hubble constants, and the existence of stars apparently older than the Universe. Under natural assumptions TGD predicts same optical properties of the large scale Universe as inflationary scenario does. The recent balloon experiments however favor TGD inspired cosmology.

### 5.3.4 TGD and Astrophysics

In this chapter some applications of TGD based view about cosmology and astrophysics are discussed.

p-Adic length scale hypothesis can be applied in astrophysical length scales, too and some examples of possible applications are discussed. One of the most interesting implications of p-adicity is the possibility of series of phase transitions changing the value of cosmological constant behaving as  $\Lambda \propto 1/L^2(k)$  as a function of p-adic length scale characterizing the size of the space-time sheet.

A model for the solar magnetic field as a bundle of topological magnetic flux tubes is constructed and a model of Sunspot cycle is proposed. This model is also shown to explain the mysteriously high temperature of solar corona and also some other mysterious phenomena related to the solar atmosphere. A direct connection with the TGD based explanation of the dark energy as magnetic and  $Z^0$  magnetic energy of the magnetic flux tubes containing dark matter as ordinary matter, emerges. The matter in the solar corona is simply dark matter leaked from the highly curved portions of the magnetic flux tubes to the space-time sheets where it becomes visible. The generation of anomalous  $Z^0$  charge caused by the runoff of dark neutrinos in Super Nova could provide a first principle explanation for the avoidance of collapse to black-hole in Super Nova explosion.

D. Da Rocha and Laurent Nottale have proposed that Schrödinger equation with Planck constant  $\hbar$  replaced with what might be called gravitational Planck constant  $\hbar_{gr} = \frac{GmM}{v_0}$  ( $\hbar = c = 1$ ).  $v_0$  is a velocity parameter having the value  $v_0 = 144.7 \pm .7$  km/s giving  $v_0/c = 4.6 \times 10^{-4}$ . This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of  $v_0$  seem to appear. The support for the hypothesis coming from empirical data is impressive.

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

problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale.

I have proposed already earlier the possibility that Planck constant is quantized. The spectrum is given in terms of integers  $n$  characterizing the quantum phases  $q = \exp(i\pi/n)$ . The Planck constants associated with  $M^4$  and  $CP_2$  degrees of freedom are predicted to be different in general and arbitrarily large values of Planck constants are possible so that  $\hbar_{gr} = GMm/v_0$  can be understood in this framework. The general philosophy would be that when the quantum system would become non-perturbative, a phase transition increasing the value of  $\hbar$  occurs to preserve the perturbative character. This would apply to QCD and to atoms with  $Z > 137$  as well.

The integers  $n$  which correspond to  $n$ -polygons constructible using ruler and compass are number theoretically preferred. This gives very strong constraints on planetary masses, their general mass scale, and also on the value of  $v_0$ . The constraints are satisfied with accuracy better than 10 per cent.

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

Long ranged classical electro-weak and color gauge fields are unavoidable in TGD framework. The smallness of the parity breaking effects in hadronic, nuclear, and atomic length scales does not however seem to allow long ranged electro-weak gauge fields. The problem disappears if long range classical electro-weak gauge fields are identified as space-time correlates for massless gauge fields created by dark matter. The identification explains chiral selection in living matter and unbroken  $U(2)_{ew}$  invariance and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

The last section of the chapter is devoted to some astrophysical and cosmological anomalies such as the apparent shrinking of solar system observed by Masreliez, Pioneer anomaly, Flyby anomaly and new anomalies in cosmic microwave background.

## 5.4 PART III: Topological field quantization

Topological field quantization is perhaps the most important signature differentiating between Maxwellian and TGD based gauge field concepts. What happens that space-time surface decomposes into regions characterized by a handful of vacuum quantum numbers. These quantum numbers partially characterize the coordinate dependence of the two phase angles  $\Psi$  and  $\Phi$  associated the two complex coordinates of  $CP_2$ .

Topological field quanta have in general outer boundary and renormalization group invariance suggests that all sizes are possible so that 3-space should have a hierarchical, fractal like, structure containing 3-surfaces condensed on each other. Not only atoms and molecules but also macroscopic bodies correspond to 3-surfaces with outer boundary so that the visible world of the everyday life can be interpreted in completely new manner: instead of topologically trivial space  $E^3$  with mysterious material objects we see empty but topologically extremely rich 3-space: the outer boundaries of the material objects correspond to the boundaries of this 3-space. Topological field quanta can be partially joined together along their boundaries (join along boundaries bond). At the level of chemistry this means the formation of chemical bond, at macroscopic level macroscopic bodies touch each other. An exciting possibility is that the formation of macroscopic quantum systems from smaller units is possible by the formation of the joining along boundaries bonds.

All this suggests that topological field quantization might provide the first principle explanation

for the generation of both spatial and temporal structures so that  $CP_2$  geometry would manifest itself in all length scales, in particular at the visible structures of the everyday world and the last part of the book is devoted to some more detailed applications of these ideas.

#### 5.4.1 Hydrodynamics and $CP_2$ geometry

The chapter begins with a brief summary of the basic notions related to many-sheeted space-time. A generalization of hydrodynamics to a p-adic hierarchy of hydrodynamics is performed and a mechanism of energy transfer between condensate levels is identified. Mary Selvam has found a fascinating connection between the distribution of primes and the distribution of vortex radii in turbulent flow in atmosphere. These observations provide new insights into p-adic length scale hypothesis and suggest that TGD based generalization of Hawking-Bekenstein law holds even in macroscopic length scales and that hydrodynamical vortices behave in some aspects like elementary particles. TGD leads to a formulation of a general theory of phase transitions: the new element is the presence of several condensate levels.

A topological model for the generation of the hydrodynamical turbulence is proposed. The basic idea is that hydrodynamical turbulence can be regarded as a spontaneous Kähler magnetization leading to the increase the value of Kähler function and therefore of the probability of the configuration. Kähler magnetization is achieved through the formation of a vortex cascade via the decay of the mother vortex by the emission of smaller daughter vortices. Vortices with various values of the fractal quantum number and with sizes related by a discrete scaling transformation appear in the cascade. The decay of the vortices takes place via the so called phase slippage process.

An encouraging result is the prediction for the size distribution of the vortices: the prediction is practically identical with that obtained from the model of Heisenberg but on rather different physical grounds. The model is rather insensitive to the p-adic scaling of vortices in the transition as long as it is smaller than  $\lambda = 2^{-5}$ . The model is also consistent with the assumption that the decay of a vortex to smaller vortices corresponds to a phase transition from a given level of dark matter hierarchy to a lower level so that the value of  $\hbar$  is reduced by a factor  $\lambda = v_0/n \simeq 2^{-11}/n$ ,  $n = 1, 2, \dots$  so that Compton length scales as well as sizes of vortices are reduced by this factor.

#### 5.4.2 Macroscopic quantum phenomena and $CP_2$ geometry

A TGD inspired description of super conductivity, super fluidity and quantum Hall effect is suggested. Contrary to the original expectation, it is found that TGD based ideas should provide new insights also to the description of less exotic condensed matter phenomena: say the description of the conductors, di-electrics and magnetism, too.

1. The basic assumption is that supra phases correspond to the small vacuum quantum number limit of TGD. At this limit the sizes of the topological field quanta becomes small (typically of the size of the coherence length of the supra phase:  $\xi = 10^{-8} - 10^{-7}$  meters for super conductors). Supra phase corresponds to a phase obtained by gluing these field quanta together by join along boundaries bonds to form a macroscopic quantum system: the presence of these bonds (or rather bridges) makes possible dissipation free flow.
2. The generation of the vacuum Kähler and  $Z^0$  fields suggests a possible unification for the classical descriptions of the super fluidity and super conductivity: the role of the magnetic field is taken by the  $Z^0$  magnetic field in the super fluidity.

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