Spin Glasses, Complexity, and TGD

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Abstract

Spin glasses represent an exotic phenomenon, which remains poorly understood in the standard theoretical framework of condensed matter physics. Actually, spin glasses provide a prototype of complex systems and methods used for spin glasses can be applied in widely different complex systems.

In this chapter a TGD inspired view about spin glasses is discussed.

1. TGD view about space-time leads to the notion of magnetic flux tubes and magnetic body. Besides spins also long closed magnetic flux tubes would contribute to magnetization. The basic support for this assumption is the observation that the sum of the NFC magnetization and the FC remanence is equal to the NFC magnetization. Magnetic field assignable to spin glass would correspond to a kind of flux tube spaghetti and the couplings J_{ij} between spins would relate to magnetic flux tubes connecting them.
2. Quantum TGD leads to the notion of "world of classical worlds" (WCW) and to the view about quantum theory as a "complex square root" of thermodynamics (of partition function). The probability distribution for $\{J_{ij}\}$ would correspond to ground state functional in the space of space-time surfaces analogous to Bohr orbits.
3. Spin glass is a prototype of a complex system. In the TGD framework, the complexity reduces to adelic physics fusing real physics with various p-adic physics serving as correlates of cognition. Space-time surfaces in $H = M^4 \times CP_2$ correspond to images of 4-surfaces $X^4 \subset M^8_c$ mapped to H by $M^8 - H$ duality. X^4 is identified as 4-surface having as holographic boundaries 3-D mass shells for which the mass squared values are roots of an octonionic polynomial P obtained as an algebraic continuation of a real polynomial with rational coefficients. The higher the degree of P, the larger the dimension of the extension of rationals induced by its roots, and the higher the complexity: this gives rise to an evolutionary hierarchy. The dimension of the extension is identifiable as an effective Planck constant so that high complexity involves a long quantum coherence scale.

   TGD Universe can be quantum critical in all scales, and the assumption that the spin glass transition is quantum critical, explains the temperature dependence of NFC magnetization in terms of long range large h_{eff} quantum fluctuations and quantum coherence at critical temperature.
4. Zero energy ontology predicts that there are two kinds of state function reductions (SFRs). "Small" SFR would be preceded by a unitary time evolution which is scaling and generated by the scaling generator L_0. This conforms with the fact that relaxation rates for magnetization obey power law rather than exponent law. "Big" SFRs would correspond to ordinary SFRs and would change the arrow of time. This could explain aging, rejuvenation and memory effects.
5. Adelic physics leads to a proposal that makes it possible to get rid of the replica trick by replacing thermodynamics with p-adic thermodynamics for the scaling operator L_0 representing energy. What makes p-adic thermodynamics so powerful is the extremely rapid converges of Z in powers of p-adic prime p.

1 Introduction

Two seminar talks have served as an inspiration for this work. The first talk by Charles Newman with title "Spin Glasses and Complexity" (`https://cutt.ly/DYiBFf6`) made clear that spin glasses represent an exotic phenomenon, which remains poorly understood in the standard theoretical framework of condensed matter physics. Actually, spin glasses provide a prototype of complex systems and methods used for spin glasses can be applied in widely different complex systems. The talk can be also found as printed version with title "Spin Glasses: Old and New Complexity" [D4] (`https://cutt.ly/EYqNncR`) The talk by Steven Thomson with title "The Physics of Spin Glasses" (`https://cutt.ly/6YiVngE`) was also very inspiring.

One particular observation, difficult to understand in the picture based on mere spins and their couplings J_{ij}, is that the sum of the magnetization produced in NFC (cooling without magnetic field) and the remanent magnetization produced in FC (cooling in presence of magnetic field) is the magnetization immediately after FC cooling has stopped and also that FC and NC magnetizations decay in a similar way. This suggests that besides spins there are also some other kinds of magnetic objects contributing to the magnetization. They would be identifiable as magnetic flux tubes in the TGD framework appearing in all scales in the TGD Universe.

The article "Aging, rejuvenation and memory: the example of spin glasses" of Eric Vincent [D2] (https://cutt.ly/vYq1egY) provides valuable information about the phenomena of aging, rejuvenation and memory, usually assigned with living matter, in spin glasses.

The puzzling observation is that the relaxation curves for magnetization are power functions rather than exponentials as expected. Could the time evolution correspond to a scaling so that the time coordinate is effectively replaced with its logarithm. This would explain the characteristic slowness of the relaxation.

These phenomena inspire the question whether the zero energy ontology (ZEO), which plays a key role in the TGD inspired description of living matter, leads to a new theory of self-organization, could play a similar role in the description of spin glasses. In ZEO unitary time evolutions between "small" state function reductions are indeed scalings rather than time translations.

1.1 Standard models of spin glass

Edwards-Anderson model [D3] (see also https://www.brandeis.edu/igert/pdfs/dasguptanotes.pdf) is the simplest model of spin glasses and assumes the distribution of bond variables J_{ij} in a lattice so that spatial disorder is absent and the disorder relates only to the couplings J_{ij} between spins. The model predicts frustration and ground state degeneracy.

In Sherrington Kirkpatrick model [D3](https://arxiv.org/abs/1211.1094) is an Ising model. Two-spin interactions with arbitrarily long range is assumed to describe the slow dynamics of the magnetization and the non-ergodic behavior of the ground state. This model is exactly solvable and relies on mean field approximation to describe the dynamics in long length scales. In the TGD framework the long range of interactions could relate to the presence of magnetic flux tubes and magnetic body (MB) inducing the long range correlations.

One must assume probability distribution for the distribution $P(\{J_{ij}\})$ of $\{J_{ij}\}$ so that one has average over the thermodynamic distributions characterized by $\{J_{ij}\}$. Free energy $F = kTlog(Z(\{J_{ij}\})$ characterizes the system for a given $\{J_{ij}\}$. One must calculate the weighted average $\langle F(\{J_{ij}\})\rangle$ using $P(\{J_{ij}\})$ as weighting. The calculation of $log(Z(\{J_{ij}\})$ is technically very demanding.

The replica trick of Giorgio Parisi [D1] https://cutt.ly/MYsbSVq relies on the formula $log(x) = lim_{n\rightarrow 0}(x^n - 1)/n$ and is used to calculate logarithm of partition function. The trick introduces a large number of copies of the system in order to calculate $log(F)$. What looks weird is that the limit $n \rightarrow \infty$ in the replica trick is just the opposite for the limit $n \rightarrow 0$!

1. The calculation of Parisi predicts a hierarchical structure of the energy landscape and this allows us to physically understand the breaking of ergodicity.

2. A further important outcome is that the energy landscape has non-Archimedean topology in which the distance between two energy minima corresponds to the height of the highest potential wall between them. This means a different topology based on a concept of nearness in the energy landscape different from that defined by the ordinary Archimedean topology.

The replica trick has very wide application to complex systems. One example is the travelling salesman problem in which one must find the shortest route connecting N cities. The different routes correspond to different permutations of N and their number increases like $N!$ increasing exponentially with N so that the problem becomes computationally intractable for larger values of N. In this case the path length serves the role of energy defined in the permutation group S_N. The challenge is to find solutions which are not far from the optimal solution. Spin glass property means that there are many solutions with nearly the same path length.

1.2 The TGD based view about spin glasses

The TGD based view about spin glasses relies on the new physics predicted by TGD.

1.2.1 Does spin glass require replacement of single space-time with the "world of classical worlds?"

1. In TGD one must give up the idea about single background space-time serving as an arena of dynamics. The arena of dynamics is identified as the "world of classical worlds" (WCW) as the space of space-time surfaces where single space-time surfaces $X^4 \subset H$ is a preferred extremal of action principle (minimal surface and extremal of the analog of Maxwell action) analogous to Bohr orbit. Preferred extremal property realizes holography. The averaging over the configurations $\{J_{ij}\}$ could correspond to the failure of the approximation assuming only single background space-time.

2. Quantum TGD could be regarded formally as a square root of thermodynamics and the vacuum functional for space-time surfaces is analogous to a complex square root of a partition function introducing a phase factor. Thermodynamic partition function could perhaps be regarded as moduli squared for the vacuum functional.

1.2.2 Is the new view about space-time required?

1. In TGD space-time surface is locally extremely simple but topologically very complex in all scales and this leads to the notion of many-sheeted space-time. TGD based notion of field differs from that of gauge theories and this leads to the notion of field body, in particular magnetic body.

2. The notions of magnetic flux tube and flux sheet are central in quantum TGD and characterizes dynamics in all scales. There are two kinds of flux tubes: monopole flux tubes not possible in Maxwellian world and non-monopole flux tubes. These flux tubes could give rise to a new magnetic degree of freedom not present in spin models and modelled in terms of J_{ij}. The strange connection between magnetizations for FC and NFC spin glasses supports this proposal.

   Also long flux tubes connecting distant spins are possible and one can think that the magnetic field of the flux gtube induced magnetization of spins along the flux tube. One could think that the spin glass corresponds to a kind of flux tube spaghetti. In this picture the Sherrington-Kirkpatrick model with couplings J_{ij} between arbitrarily distant spins would make sense physically. The distribution for $\{J_{ij}\}$ would correspond to a distribution for flux tube configurations characterized by ground state vacuum functional.

1.2.3 Is adelic physics needed to describe complexity?

Spin glasses are complex systems and the basic question concerns the proper description of complexity.

1. Number theoretic vision is an essential part of TGD. Adelic physics unifies real and various p-adic physics identified as physical correlates of cognition present in all scales to a single coherent whole.

2. M^8-H duality provides realization of duality between number theoretic physics and quantum physics as geometry generalizing Einstein's geometrization program. 4-surfaces in M^8 serve analogs of 4-D momentum space whereas ordinary space-time corresponds to a 4-surface in $H = M^4 \times CP_2$.

   In M^8 the 4-surfaces correspond to the "roots" of polynomials P with real coefficients continued to octonionic polynomials and each 4-surface corresponds to some algebraic extension of rationals inducing algebraic extension of p-adics for all values of prime p. This gives rise to an infinite hierarchy of increasingly complex extensions of rationals. This evolutionary hierarchy would provide a universal description of complexity.

3. The dimension of the extension of rationals is identified as effectively Planck constant $h_{eff} = nh_0$, where h_0 is the minimum value of Planck constant. The larger than the value of h_{eff} the longer the associated scales of quantum coherence. The phases with $h_{eff} > h$ behave in many respects like dark matter with respect to ordinary matter although they need not correspond to galactic dark matter assigned to as energy and matter to long flux tubes.

4. Since p-adic topologies are ultrametric, the natural question is whether a p-adic variant of thermodynamics for some selected p-adic prime, originally developed to describe particle massivation in the TGD framework, could provide a natural model for the thermodynamics of a given spin glass.

   Could the replica trick be replaced with p-adic thermodynamics? p-Adic thermodynamics is for the scaling generator L_0 appearing in conformally invariant quantum field theories rather than for the time translation generator as in ordinary thermodynamics. If time evolution corresponds to a scaling, the relaxation curves are predicted to be power functions rather than exponentials, as indeed observed.

   One can also ask whether the spin glass energy landscape is smooth in some p-adic topology based on the notion of nearness for which the numbers x and $x + p^n$ are near to each other for large values of n.

1.2.4 Zero energy ontology

The quantum measurement theory of TGD provides a solution to the basic interpretational issues of quantum theory. It relies on ZEO, which predicts that there are two kinds of state function reductions (SFRs).

1. "Big" SFRs (BSFRs) correspond to ordinary state function reductions and in BSFRs the arrow of time changes. BSFRs force a generalization of thermodynamics and also to a new view about self-organization, in particular of homeostasis in living matter. Also a view about conscious memories emerges and phenomena like rejuvenation could be understood in terms of time reversed evolutions. Could the phenomena of rejuvenation and aging be understood in ZEO?

2. "Small" SFRs (SSFRs) correspond to "weak measurements" following unitary time evolutions which are not time translations but scalings. The arrow of time is preserved in SSFRs. If the scaling is same for all SSFRs and therefore a constant translation for logarithmic time, the time lapse between two subsequent SSFRs increase exponentially during time evolution by SSFRs and this could explain the presence of very long time scales and also the very slow rates for the decay of M, which are not exponential but obey in good approximation power law.

3. The natural conjecture is that the time evolution by BSFRs as time translations leads to the exponential decay rates and the time evolution by SSFRs as scalings to the power laws.

1.2.5 Brief summary of TGD view

The basic new ideas behind TGD view are as follows.

1. The basic notion is that of magnetic body (MB), MB carries spin 1 Cooper pairs of dark electrons with members at parallel flux tubes as $h_{eff} > h$ variants of ordinary electrons behaving like dark matter and present below T_g, explains the long range quantum correlations and fluctuations characterizing spin glasses.

   Spin 1 Cooper pair is the simplest Galois bound state that one can imagine. Also 4-electron bound states have been observed and in TGD inspired biology bound states of 3 protons and even bound N proton triplets are proposed as Galois bound states.

2. Quantum criticality of the spin 1 Cooper pairs is second key notion. The energy of a generic state increases with h_{eff}. The binding energy of the Cooper pair must compensate for this increase and at T_g the two energies compensate but not below T_g. Hence the density of the Cooper pair condensate decreases below T_g. This explains why susceptibility decreases below T_g rather than increasing as in paramagnetism or staying constant as in ferromagnetism.

3. Zero energy ontology (ZEO) and quantum criticality of the dark electron phase explain the aging, memory, and rejuvenation phenomena in terms of a new view about what happens in state function reduction.

There are intriguing biological analogies. Memory effect implying dependence of susceptibility on thermal history suggests an interpretation as associative learning. One can ask whether aging in the case of AC stimulus (at least) corresponds to learning as an adaptation to a repeated stimulus.

The quantum criticality of the dark electron condensate makes the system an ideal sensor. Sudden stimulus, such as reduction or increase of temperature or addition of external magnetic field H, would cause a shock and the associated energy feed would generate dark electron pairs and increase susceptibility as a reactivity to stimulus.

The difficult-to-understand return of the system to its state before the perturbation started in the negative temperature system has a natural interpretation as BSFR in the model explaining sleep as a time reversed state induced by BSFR as well as after images.

4. p-Adic physics conforms with the ultrametric topology of energy landscape and suggests the replacement of the ordinary unitarity time evolution with scaling and of the ordinary thermodynamics with p-adic thermodynamics for the scaling generator L_0. This explains why the relaxation obeys power law rather than exponential law. This allows also to replace the replica trick with mathematically well-defined p-adic thermodynamics.

2 Basic facts about spin glasses as complex systems

Spin glass represents a proto type of a complex system. Complex systems differ from ordered systems of condensed matter physics in that they do not have high symmetries making their mathematical description simple. Crystals have translational symmetry. For amorphous systems like glass the spatial translational symmetries are lost and the behavior of glass is not time invariant. In some sense, glasses are between fluids and solids (the generally held belief that glasses flow downwards in the gravitational field is however wrong). Temporal fluctuations appear in very long time scales. In magnetic systems spin is added as an additional degree of freedom to each point. Ferromagnets and antiferromagnets are ordered systems whereas paramagnets are magnetically disordered and the isorder is thermodynamically induced.

In spin glasses spatial and magnetic order are lost but not thermodynamically. One can imagine that spin glass consists of small regions, whose magnetization direction varies. One could perhaps even say that spin glasses are partially ferromagnetic and partially antiferromagnetic and that the competition between ferro- and antiferromagnetism determines their character.

2.1 Preparation of spin glass phase

The following is a short layman summary about how spin glasses are prepared and what their basic properties are based on the articles [D4, D2]. Spin glasses are not ideal but strongly diluted magnetic alloys obtained from metallic alloys or insulators by adding a small amount of impurity.

1. The so called RKKY interaction (`https://cutt.ly/XYiMsSV`), where RKKY stands for Ruderman–Kittel–Kasuya–Yosida, is believed to be the coupling mechanism of nuclear magnetic moments or localized inner d- or f-shell electron spins in a metal by means of an interaction through the conduction electrons.

   In the case of spin glasses, the interaction would be an indirect interaction between the inner electron spins induced by their interaction with the spins of the conduction electrons. The intereaction Hamiltonian oscillates as a function of distance R between inner electrons and decreases like $1/R^3$.

2. The canonical example of spin glass is obtained from both 3 per cent Mn ions in Cu produces a metallic alloy. Cu itself is non-magnetic. The locations of Mn ions are random so that the oscillating character of RKKY interaction makes the sign of the couplings J_{ij} random. In thermodynamics one must also average over the distribution of $\{J_{ij}\}$. Historically, this class of systems were the first spin glasses discovered.

3. Also insulating compounds are possible. For instance, one can start from a ferromagnet and remove some magnetic Cr ions. In [D2] Indium diluted Chromium thiospinel $CdCr_{2x}In_{2(1-x)}$

S_4, with superexchange magnetic interactions between the Cr ions, is mentioned as an example. Note that x refers to average stoichiometry.

For $x = 1$ this compound is a ferromagnet with Curie temperature T_c=80 K. The nearest neighbor couplings are ferromagnetic and dominate for $x = 1$ but next neighbor couplings are antiferromagnetic. When some magnetic Cr ions are replaced with non-magnetic In ions, the effect of antiferromagnetic interactions is enhanced. The ferromagnetism is replaced with spin glass phase for $x \leq .85$.

The critical temperature T_g for the transition to spin glass phase is in the range 1-100 K. Field cooling (FC) occurring in presence of magnetic field H, and the cooling in absence of magnetic field (NFC) are the basic methods to achieve spin glass phase. The field strengths used in cooling are of order Oersted: 1 Gauss. Stronger magnetic fields destroy the spin glass phase. It might not be an accident that the magnetic field of Earth is about .5 Gauss and that the "endogenous" magnetic field of strength about .2 Gauss is of utmost importance in the TGD based quantum model of the living system.

2.2 What happens in the spin glass phase transition?

The transition to spin glass involves two critical temperatures.

1. There is an asymmetric peak in the magnetic susceptibility at critical temperature T_g for the spin glass transition.

2. A broad maximum in specific heat occurs at temperature T_{g1}, which is 10-30 per cent higher than T_g. Note that also specific heat increase roughly linearly below T_g which is not a standard

Remark: The idea of a unique critical temperatures T_g and Tg_1 can be challenged: Anderson has proposed in his cluster model of spin glass that the critical temperature is cluster dependent (`https://cutt.ly/LYi4YvN`). The large scale of variation of J_{ij} and rugged energy landscape would indeed conform with a hierarchy of critical temperatures. The broad maximum in specific heat could correspond to a cluster of peaks associated with different critical temperatures T_{g1}.

Spin glass can be cooled in the presence of a magnetic field, this is field cooling (FC), or without magnetic field (NFC) (see Fig. 1.2 of [D2] `https://cutt.ly/vYq1egY`). In FC, M/H as function T is measured during the cooling. The typical value of H is 10 Gauss. In NFC, the magnetic field H is coupled on after NFC and T is increased gradually and M/H measured as a function of T.

FC and NFC give different temperature behavior of the magnetization M/H below T_g. FC produces a stronger magnetization, which is almost constant below T_g. In ZFC, the magnetization decreases with temperature $T < T_g$.

2.3 Basic properties of spin glasses

The following list gives the basic characteristics of spin glasses.

1. Spin glasses are disordered. In general, there is both magnetic and spatial disorder although also purely magnetic disorder is in principle possible. In practical systems one however prepares spin glasses by adding a small amount (few percent) of magnetic impurity in a paramagnetic system which then generates an ordering which is partly ferromagnetic, partly antiferromagnetic. The impurity spin is assumed to induce layers with different directions of magnetization. One can of course ask, how closely these real systems correspond to an ideal spin glass.

   An important distinction as compared to paramagnets is that the disorder is not thermal. Disorder is related to both spatial locations of the impurity spins and to the spin directions and corresponds to the randomness of the couplings between spins rather than being caused by thermal fluctuations. The disorder remains at $T \to 0$ limit.

2. In the spin lattice models, the disorder is modeled in terms of a distribution of random spin interaction strengths J_{ij}, whose sign determines whether the spins tend to be parallel (ferromagnetism) or antiparallel (antiferromagnetism).

   The variation of the sign of spin-spin couplings implies that the ground state is not unique as can be seen already in the case of 3 spins. This degeneracy for states of a given energy is called frustration. It has an obvious social analogy: situations involving only 2 people are much easier for participants than situations involving at least 3 people.

   Spin glasses have a huge number of ground states and the energy of the ground state varies in a random looking manner. The change of a single spin direction can have a dramatic effect on energy.

   The outcome is a rugged energy landscape with valleys inside valleys having fractal structure. This implies a failure of ergodicity (for an ergodic classical system the classical orbit goes through all possible points). Only the points of the energy landscape which can be reached within finite time can contribute to thermal averaging of a non-ergodic system. The failure of ergodicity requires non-equilibrium thermodynamics. Non-ergodicity means that during the cooling process spin glass can get stuck to a local valley.

3. There are also fluctuations in the distribution of J_{ij}. This requires averaging over the distribution of $\{J_{ij}\}$. One has probability distribution of probability distributions! One could say that a new abstraction level emerges. This occurs also in quantization of fields in which one considers the dynamics wave functions in the configuration space instead of dynamics of single configuration. One can argue that each $\{J_{ij}\}$ has its own critical temperature T_g so that one must speak of a criticality interval instead of a single critical temperature.

4. Because the heights of the potential walls in the rugged energy landscape have a finite height, spin glasses exist only at low temperatures below the critical temperature T_g. A typical value for T_g is in the range $1-100$ K, which corresponds to an energy of 3 meV. At high temperatures the system transforms to a paramagnet. The corresponding energy is in the range $1-10^{-2}$ eV.

   The ruggedness of the energy landscape implies that the outcome of the cooling is in general only a local energy minimum. In annealed cooling, discovered in the study of spin glasses, one heats the system by ΔT (quenching), allows it to be in this state for some time and then cools it: this process can be repeated by reducing the temperature increment ΔT gradually.

5. The dynamics of spin glasses is slow and involves several time scales and there seems to be no bound for these time scales. The phenomena of aging, rejuvenation, and memory [D2] are analogous to corresponding phenomena in living matter and make spin glasses especially fascinating systems. One can ask whether spin models are enough for the understanding of these phenomena.

How can one distinguish between spin glasses and other magnetic systems?

1. The thermal properties of spin glass differ from those of other magnetic systems. In particular, specific heat increases linearly as a function of temperature (`https://cutt.ly/LYi4xK2`) corresponding to electronic specific heat `https://cutt.ly/tYohORe`. At very low temperatures there is a $1/T^2$ hyperfine contribution and at higher temperatures phononic T^3 contribution.

2. An important feature of spin glasses is that the time dependence of spin-spin correlation functions is very slow, which means approximately ferromagnetic behavior. In paramagnets the correlation function decays rapidly.

3. The temporal behavior of spin glass magnetization M during and after the cooling is an important source of information. There are two basic methods to prepare spin glass phases: field cooling (FC) in presence of magnetic field H and the cooling in absence of magnetic fields (NFC): M/H as function T is measured after NC by increasing the temperature gradually.

   The magnetization M of the final state is different for FC and NFC and distinguishes spin glasses from paramagnets. The temperature dependent magnetization M immediately after cooling is considerably smaller in NFC than in FC and for FC M depends only weakly on temperature and has a small peak around critical temperature T_g.

After the removal of H, M decays slowly. For FC, M approaches to a remnant magnetization (remanence) characterizing ferromagnets whereas for NFC M approaches zero. Remarkably, the rates of decrease for FC and NFC magnetization are the same. As if FC magnetization would consist of a sum of NFC magnetization and remanence. Do ordinary ferromagnetic electrons give the remanence and is the NFC magnetization produced by entities, which are not ordinary electrons?

4. As already mentioned, the transition to spin glass phase takes place at temperature T_g between $1-100$ K which is roughly proportional to the doping ratio r of impurity atoms. A typical value of H is 10 G. In NFC there is a sharp peak in magnetization M at T_g. There is however a broad maximum in heat capacity at a temperature $T_{g1} > T_g$ and the physical interpretation of this peak is not well-understood. Could it relate to the presence of entities, which are not electron spins? Why do they produce no magnetization?

   This suggests also a connection with high T_c superconductivity for which one also has two temperatures T_c and T_{c1}. Cooper pairs appear at T_{c1} and superconductivity at T_c. Could spin 1 Cooper pairs produce the NFC magnetization.

   Remark: In the TGD framework, the Cooper pairs would be dark and thus have $h_{eff} > h$. One option is that the dark Cooper pairs appearing at T_{g1} have spin $s = 0$ and produce no magnetization. The Cooper pairs appearing at T_g could have $s = 1$ and produce dark magnetization?

One can raise several questions concerning the models of spin glasses. What determines J_{ij} used to model spin glasses (here RKKY model is the general proposal)? Are the couplings J_{ij} fundamental and could the distribution of J_{ij} model something at a deeper level? Are the spin degrees of freedom enough for understanding spin glasses or is there something else, perhaps some other kinds of magnetic entities besides spins, which could allow us to understand the distribution of J_{ij}?

2.4 Aging and rejuvenation in spin glasses

The article of Eric Vincent [D2] (`https://cutt.ly/vYq1egY`) provides information about aging, rejuvenation and memory in spin glasses. These phenomena occur also in other glassy systems such as structural and polymer glasses, colloids, gels etc..

The basic experiments in which glassy dynamics is commonly investigated can be presented in 3 general classes: dc response, ac response, and spontaneous fluctuations (noise). The article of Vincent discusses the scaling laws used to describe the isothermal aging observed after quench down to the low temperature phase. The scaling laws are the same for polymer glasses.

A crucial feature of the spin-glass behavior (and of glassy dynamics in general) is the existence of relaxation processes at all time scales, from the microscopic times ($\sim 10^{-12}$ s in spin glasses) to, at least, as long as the experimentalist can wait. The slow relaxation processes are particularly spectacular: in a spin glass, any field change causes a very long-lasting relaxation of the magnetization, and the response to an ac field is noticeably delayed.

Also rejuvenation and memory effects observed when spin glass is submitted to temperature variations during again, are discussed. The implications of rejuvenation and memory effects are considered both in the energy landscape picture and real space picture. Both approaches point out to the necessity of hierarchical processes involved in aging. The article introduces strongly temperature dependent dynamical correlations.

DC aging can assigned with FC and NFC. Also AC aging under oscillator perturbations as well as spontaneous fluctuations as function of age of the system can be studied.

1. In FC aging, the spin glass is submitted to a magnetic field H in Gauss scale for time t_w after the cooling process has stopped. The relaxation time for magnetization M is the longer the

longer t_w is. M/M_{FC} is measured as a function of time. The relaxation becomes slower as t_w increases. One can say that during t_w aging occurs and somehow changes the properties of the system.

2. In ZFC aging, the field is turned on after t_w: M_{ZFC}/M_{FC} increases as t_w increases. Also now relaxation curves depend on t_w and FC and M increases after that and approach to its value for FC. FCD and ZFC cases look like time reversals of each other. An approximate t/t_w scaling is observed.

How does aging manifest itself in the relaxation of magnetization?

1. In the lowest order approximation, the relaxation is logarithmic. Actually it seems that in improved approximation the evolution corresponds to a small power $(t/t_w)^\alpha$, $\alpha \sim .07$, of time. If one expands this as powers of $u = log(t/t_w)$, the lowest approximation gives a logarithmic behavior.

2. One attempt to interpret this behavior is by assuming a distribution $P(t)$ of effective relaxation times t associated exponential decay. Distribution of effective relaxation times t (not the physical time) is parametrized by t_w strongly distributed around t_w.

   Is this assumption really necessary? Could one understand the relaxation time in terms of scaling covariance predicting a power law. One can go even further and ask if evolution as time translation is replaced with scaling so that $t - t_w$ replaced by t/t_w. This is equivalent with the assumption that time translations act on logarithmic time $u = t/t_w$.

   This would fit naturally with a quantal time evolution as scaling defined by the exponential of the scaling operator L_0 for conformally invariant systems (in TGD this would correspond to scaling evolution by SSFRs). Relaxation would be with respect to time $u = log(t/t_w)$ and α would be analogous to decay time t.

3. The scaling is not exact and the parameterization. The deviations from scaling are systematic and are discussed in [D2]: see Fig. 2.4 (`https://cutt.ly/vYq1egY`), where the notion of sub-aging is introduced. AC experiments give no sign of sub-aging.

The memory effects described in the article are associated with mechanical stress or a temporary reduction of temperature. The relaxation seems to restart from the earlier value of magnetization and continue in the same manner. When the original temperature is returned, the relaxation restarts from the moment when the temperature was reduced. One could say that a rejuvenation by a return to the original situation takes place. Fig. 3.3 of [D2] (`https://cutt.ly/vYq1egY`) gives an idea about what occurs.

3 TGD very briefly

3.1 WCW picture

Probability distribution for probability distription of spins suggests that a totalluy new level of dynamics is involved.

Q: What does this distribution correspond to at fundamental level? A: In TGD this would correspond to the "world of classical worlds" (WCW).

WCW ground state corresponds to vacuum functional determined as exponent of Kaehler function and determines a wave function in the space of preferred extremals corresponds to the distribution over J_{ij}. Quantum analog of Z. Square root of thermodynamis. Vacuum functional is analogous to complex square root of Z. Z as its modulus squared.

Quantum spin glass (physics is quantal in all scales in TGD!). Thermal state replaced with WCW zero energy state with wave function in the space of flux tube patterns. Given flux tube pattern preferred extremal analogous to Bohr orbit. Extremely ordered. Wave function over these. Quantum superposition of different configurations would correspond to the probability distribution for $\{J_{ij}\}$.

3.2 Number theoretical physics

3.2.1 Adelic physics very briefly

Number theoretic vision leading to adelic physics [L5] provides a general formulation of TGD complementary to the vision [K10] (http://tinyurl.com/sh42dc2) about physics as geometry of "world of classical words" (WCW).

1. p-Adic number fields and p-adic space-time sheets serve as correlates of cognition. Adele is a Cartesian product of reals and extensions of all p-adic number fields induced by given extension of rationals. Adeles are thus labelled by extensions of rationals, and one has an evolutionary hierarchy labelled by these extensions. The large the extension, the more complex the extension which can be regarded as $n-D$ space in K sense, that is with K-valued coordinates.

2. Evolution is assigned with the increase of algebraic complexity occurring in statistical sense in BSFRs, and possibly also during the time evolution by unitary evolutions and SSFRs following them. Indeed, in [L14] (http://tinyurl.com/quofttl) I considered the possibility that the time evolution of self in this manner could be induced by an iteration of polynomials - at least in approximate sense. Iteration is a universal manner to produce fractals as Julia sets and this would lead to the emergence of Mandelbrot and Julia fractals and their 4-D generalizations. In the sequel will represent and argument that the evolution as iterations could hold true in exact sense.

   Cognitive representations are identified as intersection of reality and various p-adicities (cognition). At space-time level they consist of points of embedding space $H = M^4 \times CP_2$ or M^8 ($M^8 - H$ duality [L2, L3, L4] allows to consider both as embedding space) having preferred coordinates - M^8 indeed has almost unique linear M^8 coordinates for a given octonion structure.

3. Given extension of given number field K (rationals or extension of rationals) is characterized by its Galois group leaving K - say rationals - invariant and mapping products to products and sums to sums. Given extension E of rationals decomposes to extension E_N of extension E_{N-1} of ... of extension E_1 - denote it by $E \equiv H_N = E_N \circ E_{N-1} ... \circ E_1$. It is represented at the level of classical space-time dynamics in M^8 (http://tinyurl.com/quofttl) by a polynomial P which is functional composite $P = P_N \circ P_{N-1} \circ ... \circ P_1$. with $P_i(0) = 0$. The Galois group of $G(E)$ has the Galois group $H_{N-1} = G(E_{N-1} \circ ... \circ E_1)$ as a normal subgroup so that $G(E)/H_{N-1}$ is group.

   The elements of $G(E)$ allow a decomposition to a product $g = h_{N-1} \times h_{N-1} \times ...$ and the order of $G(E)$ is given as the product of orders of H_k: $n = n_0 \times .. \times n_{N-1}$. This factorization of prime importance also from quantum point of view. Galois groups with prime order do not allow this decomposition and the maximal decomposition and are actually cyclic groups Z_p of prime order so that primes appear also in this manner.

   Second manner for primes to appear is as ramified primes p_{ram} of extension for which the p-adic dynamics is critical in a well-defined sense since the irreducible polynomial with rational coefficients defining the extension becomes reducible (decomposes into a product) in order $O(p) = 0$. The p-adic primes assigned to elementary particles in p-adic calculation have been identified as ramified primes but also the primes labelling prime extensions possess properties making them candidates for p-adic primes.

   Iterations correspond to the sequence $H_k = G_0^{\circ k}$ of powers of generating Galois groups for the extension of K serving as a starting point. The order of H_k is the power n_0^k of integer $n_0 = \prod p_{0i}^{k_i}$. Now new primes emerges in the decomposition of n_0. Evolution by iteration is analogous to a unitary evolution as ex^{iHt} power of Hamiltonian, where t parameter takes the role of k .

4. The complexity of extension is characterized by the orders n and the orders n_k as also the number N of the factors. In the case of iterations of extension the limit of large N gives fractal.

5. At space-time level, Galois group acts in the space of cognitive representations and for Galois extensions for which Galois group has same order as extensions, it is natural do consider quantum states as wave functions in $G(E)$ forming n-D group algebra. Therefore Galois groups becomes physical symmetry groups.

   One can assign to the group algebra also spinor structure giving rise to $D = 2^{M/2}$ fermionic states where one has $N = 2M$ or $N = 2M + 1$). One can also consider chirality constraints reducing D by a power of 2. An attractive idea is that this spinor structure represents many-fermion states consisting of $M/2$ fermion modes and providing representation of the fermionic Fock space in finite measurement resolution.

Adelic physics [L5], $M^8 - H$ duality [L12, L13, L22, L28], and zero energy ontology (ZEO) [L11, L24, L23] lead to a proposal [L17] that the dynamics involved with "small" state function reductions (SSFRs) as counterparts of weak measurements could be basically number theoretical dynamics with SSFRs identified as reduction cascades leading to completely un-entangled state in the space of wave functions in Galois group of EQ identifiable as wave functions in the space of cognitive representations. As a side product a prime factorization of the Galois group to simple factors as normal subgroups is obtained.

The result looks even more fascinating if the cognitive dynamics is a representation for the dynamics in real degrees of freedom in finite resolution characterized by the extension of rationals. If cognitive representations represent reality approximately, this indeed looks very natural and would provide an analog for adele formula expressing the norm of a rational as the inverse of the product of is p-adic norms. The results can be appplied to the TGD inspired model of genetic code.

3.2.2 Dark matter as hierarchy of phases of ordinary matter with $h_{eff} = n \times h_0$

The first new element is the hierarchy of Planck constants $h_{eff}/h = n$. In adelic physics [L6, L5] proposed to provide physical correlates of both sensory experience and cognition $h_{eff}/h = n$ serves as a kind of IQ for the system measuring its algebraic complexity (n could correspond to the order of the Galois group for the extension of rationals defining the adele in question).

1. Quantum criticality is the basic property of TGD Universe and also an essential aspect of what it is to be living in TGD Universe and the associated long range fluctuations and correlations correspond to large values of $h_{eff}/h = n$ for the flux tubes of MB [?]. The increase of $h_{eff}/h = n$ keeping magnetic field strength un-affected reduces binding energies for electrons of atoms and increases cyclotron energy scale and scales up quantum lengths and times, in particular the scales of quantum coherence and this kind of phase transitions seem to be crucial in TGD inspired biology.

   The energies of subsystems indeed typically increase with h_{eff}. For instance, atomic binding energies are proportional to $1/h_{eff}^2$. Cyclotron energies are in turn proportional to h_{eff}.

   The function of metabolism in TGD Universe is to increase the value of h_{eff} for some subsystems of living system, and therefore to increase the complexity of the subsystem. The reduction of h_{eff} liberates energy and this energy could kick the reacting molecules over the potential wall in bio-catalysis. The reduction of n forcing the shortening of the flux tubes could provide a mechanism allowing the reacting biomolecules to find each other in a dense molecular soup.

2. The cyclotron frequencies of dark ions in the magnetic field of the flux tubes do not depend on $h_{eff}/h = n$ but the cyclotron energies $E_c = h_{eff} \times f$ are scaled up by factor n so that they are above thermal energy at physiological temperatures and can carry information so that they can be used for communication and control purposes. Cell membrane acts as a generalized Josephson junction and dark Josephson radiation communicates sensory information to MB coded to the modulation of the generalized Josephson frequency by the variations of neuronal membrane potential induced by nerve pulse patterns [K9, K6].

3.2.3 $h_{gr} = h_{eff}$ hypothesis and universal cyclotron energies

$h_{gr} = h_{eff}$ hypothesis [K8, ?] and its generalizations such as e $h_{em} = h_{eff}$ represent a further key element of the TGD inspired model of living matter. This relationship is proposed to hold when the coupling strength proportional to appropriate charges is so large that perturbation series does not converge. The large value of h_{eff} reduces the value of coupling strength proportional to $1/h_{eff}$ so that dark matter satisfying this condition would allow a perturbative description.

1. Nottale [E1] introduced originally the notion of gravitational Planck constant $\hbar_{gr} = GMm/v_0$ to explain the orbital radii of planets in solar system as Bohr orbits. The value of the velocity parameter v_0/c is of order $2^{-11} \simeq .5 \times 10^{-3}$ for the 4 inner planets. The interpretation in TGD framework is that the magnetic flux tubes mediate gravitational interaction between masses M and m and the value of Planck constant is h_{gr} at them.

   The proposal $h_{eff} = h_{gr}$ at flux tubes is very natural sharpening of the original hypothesis [?, K8]. The predictions of the model do not depend on whether m is taken to be the mass of the planet or any elementary particle associated with it and the gravitational Compton length $\lambda_{gr} = GMc/v_0$ does not depend on the mass of the particle, and is proportional to the Schwartschild radius $r_S = 2GM$ of Sun. This encourages the idea about astroscopic quantum coherence at magnetic flux tubes mediating gravitational interaction. One of the applications is to the fountain effect of superfluidity [?].

   In the biological applications the identification of mass M as Earth mass is one possibility but there are also other options [K8]. The identification of v_0 as some mechanical velocity scale looks natural.

2. $h_{gr} = h_{eff}$ hypothesis predicts that cyclotron energies do not depend on the mass of the particle whereas cyclotron frequencies are proportional to $1/m$. Cyclotron energy spectrum would be universal and correspond to the spectrum of magnetic field strengths B. Bio-photons with energies in visible and UV are proposed to result as dark photons satisfying $h_{gr} = h_{eff}$ transform to ordinary photons. For $B = B_{end} = 2B_E/5$ ($B_E = .5$ Gauss is the nominal value of the Earth's magnetic field) the hypothesis fixes the scale of cyclotron frequencies and h_{gr} should be in the range $10^{12} - 10^{14}$.

3.2.4 $M^8 - H$ duality

$M^8 - H$ duality is one of the cornerstones of Topological Geometrodynamics (TGD). The original version of $M^8 - H$ duality assumed that space-time surfaces in M^8 can be identified as associative or co-associative surfaces. If the surface has associative tangent or normal space and contains a complex or co-complex surface, it can be mapped to a 4-surface in $H = M^4 \times CP_2$.

Later emerged the idea that octonionic analyticity realized in terms of real polynomials P algebraically continued to polynomials of complexified octonion could fulfill the dream. The vanishing of the real part $Re_Q(P)$ (imaginary part $Im_Q(P)$) in the quaternionic sense would give rise to an associative (co-associative) space-time surface.

The realization of the general coordinate invariance motivated the notion of strong form of holography (SH) in H allowing realization of a weaker form of $M^8 - H$ duality by assuming that associativity/co-associativity conditions are needed only at 2-D string world sheet and partonic 2-surfaces and possibly also at their light-like 3-orbits.

The detailed study of the proposal yielded both positive and negative surprises.

1. Although no interesting associative space-time surfaces are possible, every distribution of normal associative planes (co-associativity) is integrable.

2. The conjecture based on naive dimensional counting, which was not correct, was that the polynomials P determine these 4-D surfaces as roots of $Re_Q(P)$. The normal spaces of these surfaces possess a fixed 2-D commuting sub-manifold or possibly their distribution allowing the mapping to H by $M^8 - H$ duality as a whole.

3. The concrete calculation of the octonion polynomial was the most recent step - carried already earlier [L2, L3, L4] but without realizing the implications of the extremely simple outcome.

The imaginary part of the polynomial is proportional to the imaginary part of octonion itself. It turned out that the roots $P = 0$ of the octonion polynomial P are 12-D complex surfaces in O_c rather than being discrete set of points defined as zeros $X = 0, Y = 0$ of two complex functions of 2 complex arguments. The analogs of branes are in question. Already earlier 6-D real branes assignable to the roots of the real polynomial P at the light-like boundary of 8-D light-cone were discovered: also their complex continuations are 12-D [L8, L11].

4. P has quaternionic de-composition $P = Re_Q(P) + I_4 Im_Q(P) \equiv X + I_4 Y$ to real and imaginary parts in a quaternionic sense. The naive expectation was that the condition $X = 0$ implies that the resulting surface is a 4-D complex surface X^4_c with a 4-D real projection X^4_r, which could be co-associative.

   The expectation was wrong! The equations $X = 0$ and $Y = 0$ involve the same(!) complex argument o^2_c as a complex analog for the Lorentz invariant distance squared from the tip of the light-cone. This implies a cold shower. Without any additional conditions, $X = 0$ conditions have as solutions 7-D complex mass shells H^7_c determined by the roots of P. The explanation comes from the symmetries of the octonionic polynomial.

   There are solutions $X = 0$ and $Y = 0$ only if the two polynomials considered have a common a^2_c as a root! Also now the solutions are complex mass shells H^7_c.

How could one obtain 4-D surfaces X^4_c as sub-manifolds of H^7_c? One should pose a condition eliminating 4 complex coordinates: after that a projection to M^4 would produce a real 4-surface X^4 .

1. The key observation is that G_2 acts as the automorphism group of octonions respects the co-associativity of the 4-D real sub-basis of octonions. Therefore a local G_2 gauge transformation applied to a 4-D co-associative sub-space M^4 gives a co-associative four-surface as a real projection. Octonion analyticity would correspond to G_2 gauge transformation: this would realize the original idea about octonion analyticity.

2. A co-associative X^4_c satisfying also the conditions posed by the existence of $M^8 - H$ duality is obtained by acting with a local SU_3 transformation g to a co-associative plane $M^4 \subset M^8_c$. If the image point $g(p)$ is invariant under $U(2)$, the transformation corresponds to a local CP_2 element and the map defines $M^8 - H$ duality even if the co-associativity in geometric sense were not satisfied.

   The co-associativity of the plane M^4 is preserved in the map because G_2 acts as an automorphism group of the octonions. If this map also preserves the value of 4-D complex mass squared, one can require that the intersections of X^4_c with H^7_c correspond to 3-D complex mass shells. One obtains holography with mass shells defined by the roots of P giving boundary data. The condition H images are analogous to Bohr orbits, corresponds to number theoretic holography.

3. The group $SU(3)$ has interpretation as a Kac-Moody type analog of color group and the map defining space-time surface. This picture conforms with the H-picture in which gluon gauge potentials are identified as color gauge potentials. Note that at QFT limit the gauge potentials are replaced by their sums over parallel space-time sheets to give gauge fields as the space-time sheets are approximated with a single region of Minkowski space.

4. Octonionic Dirac equation as analog of momentum space variant of ordinary Dirac equation forces the interpretation of M^8 as an analog of momentum space and Uncertainty Principle forces to modify the map $M^4 \subset M^8 \rightarrow M^4 \subset H$ from an identification to an almost inversion. The octonionic Dirac equation reduces to the mass shell condition $m^2 = r_n$, where r_n is a root of the polynomial P defining the 4-surface but only in the co-associative case.

This picture combined with zero energy ontology leads also to a view about quantum TGD at the level of M^8. A local $SU(3)$ element defining 4-surface in M^8, which suggests a Yangian symmetry assignable to string world sheets and possibly also partonic 2-surfaces. The representation of Yangian algebra using quark oscillator operators would allow to construct zero energy states at representing the scattering amplitudes. The physically allowed momenta would naturally correspond to algebraic integers in the extension of rationals defined by P. The co-associative space-time surfaces (unlike generic ones) allow infinite-cognitive representations making possible the realization of momentum conservation and on-mass-shell conditions.

3.2.5 Galois confinement

The notion of Galois confinement emerged in TGD inspired biology [L29, L16, L18, L21]. Galois group for the extension of rationals determined by the polynomial defining the space-time surface $X^4 \subset M^8$ acts as a number theoretical symmetry group and therefore also as a physical symmetry group.

1. The idea that physical states are Galois singlets transforming trivially under the Galois group emerged first in quantum biology. TGD suggests that ordinary genetic code is accompanied by dark realizations at the level of magnetic body (MB) realized in terms of dark proton triplets at flux tubes parallel to DNA strands and as dark photon triplets ideal for communication and control [L16, L21, L20]. Galois confinement is analogous to color confinement and would guarantee that dark codons and even genes, and gene pairs of the DNA double strand behave as quantum coherent units.

2. The idea generalizes also to nuclear physics and suggests an interpretation for the findings claimed by Eric Reiter [L27] in terms of dark N-gamma rays analogous to BECs and forming Galois singlets. They would be emitted by N-nuclei - also Galois singlets - quantum coherently [L27]. Note that the findings of Reiter are not taken seriously because he makes certain unrealistic claims concerning quantum theory.

It seems that Galois confinement might define a notion much more general than thought originally and in fact suggests a univeral mechanism for the formation of bound states. To understand what is involved, it is best to proceed by making questions.

1. Why not also hadrons could be Galois singlets so that the somewhat mysterious color confinement would reduce to Galois confinement? This would require the reduction of the color group to its discrete subgroup acting as Galois group in cognitive representations. Could also nuclei be regarded as Galois confined states? I have indeed proposed that the protons of dark proton triplets are connected by color bonds [L10, L15, L1].

2. Could all bound states be Galois singlets? The formation of bound states is a poorly understood phenomenon in QFTs. Could number theoretical physics provide a universal mechanism for the formation of bound states. The elegance of this notion is that it makes the notion of bound state number theoretically universal, making sense also in the p-adic sectors of the adele.

3. Which symmetry groups could/should reduce to their discrete counterparts? TGD differs from standard in that Poincare symmetries and color symmetries are isometries of H and their action inside the space-time surface is not well-defined. At the level of M^8 octonionic automorphism group G_2 containing as its subgroup $SU(3)$ and quaternionic automorphism group $SO(3)$ acts in this way. Also super-symplectic transformations of $\delta M^4_\pm \times CP_2$ act at the level of H. In contrast to this, weak gauge transformations acting as holonomies act in the tangent space of H.

   One can argue that the symmetries of H and even of WCW should/could have a reduction to a discrete subgroup acting at the level of X^4. The natural guess is that the group in question is Galois group acting on cognitive representation consisting of points (momenta) of M^8_c with coordinates, which are algebraic integers for the extension.

   Momenta as points of M^8_c would provide the fundamental representation of the Galois group. Galois singlet property would state that the sum of (in general complex) momenta is a rational integer invariant under Galois group. If it is a more general rational number, one would have fractionation of momentum and more generally charge fractionation. Hadrons, nuclei, atoms, molecules, Cooper pairs, etc.. would consist of particles with momenta, whose components are algebraic, possibly complex, integers.

Also other quantum numbers, in particular color, would correspond to representations of the Galois group. In the case of angular moment Galois confinement would allow algebraic half-integer valued angular momenta summing up to the usual half-odd integer valued spin.

4. Why Galois confinement would be needed? For particles in a box of size L the momenta are integer valued as multiples of the basic unit $p_0 = \hbar n \times 2\pi/L$. Group transformations for the Cartan group are typically represented as exponential factors which must be roots of unity for discrete groups. For rational valued momenta this fixes the allowed values of group parameters. In the case of plane waves, momentum quantization is implied by periodic boundary conditions.

   For algebraic integers the conditions satisfied by rational momenta in general fail. Galois confinement for the momenta would however guarantee that they are integer valued and boundary conditions can be satisfied for the bound states.

3.3 Zero energy ontology

ZEO [K12] forms the cornerstone of the TGD inspired quantum theory extending to a theory of consciousness. ZEO has so far reaching consequences that it would have deserved a separate section. Since it involves in an essential manner the notion of CD, it is natural to include it to the section discussing $M^8 - H$ duality.

3.3.1 The basic view about ZEO and causal diamonds

The following list those ideas and concepts behind ZEO that seem to be rather stable.

1. GCI for the geometry of WCW implies holography, Bohr orbitology and ZEO [L11] [K12].

2. X^3 is more or less equivalent with Bohr orbit/preferred extremal $X^4(X^3)$. Finite failure of determinism is however possible [L28]. Zero energy states are superpositions of $X^4(X^3)$. Quantum jump is consistent with causality of field equations.

3. Causal diamond (CD) defined as intersection of future and past directed light cones ($\times CP_2$) plays the role of quantization volume, and is not arbitrarily chosen. CD determines momentum scale and discretization unit for momentum (see **Fig. ?? Fig. ??**).

4. The opposite light-like boundaries of CD correspond for fermions dual vacuums (bra and ket) annihilated by fermion annihilation *resp.* creation operators. These vacuums are also time reversals of each other.

   The first guess is that zero energy states in fermionic degrees of freedom correspond to pairs of this kind of states located at the opposite boundaries of CD. This seems to be the correct view in H. At the M^8 level the natural identification is in terms of states localized at points inside light-cones with opposite time directions. The slicing would be by mass shells (hyperboloids) at the level of M^8 and by CDs with same center point at the level of H.

5. Zeno effect can be understood if the states at either cone of CD do not change in "small" state function reductions (SSFRs). SSFRs are analogs of weak measurements. One could call this half-cone call as a passive half-cone. I have earlier used a somewhat misleading term passive boundary.

   The time evolutions between SSFRs induce a delocalization in the moduli space of CDs. Passive boundary/half-cone of CD does not change. The active boundary/half-cone of CD changes in SSFRs and also the states at it change. Sequences of SSFRs replace the CD with a quantum superposition of CDs in the moduli space of CDs. SSFR localizes CD in the moduli space and corresponds to time measurement since the distance between CD tips corresponds to a natural time coordinate - geometric time. The size of the CD is bound to increase in a statistical sense: this corresponds to the arrow of geometric time.

6. There is no reason to assume that the same boundary of CD is always the active boundary. In "big" SFRs (BSFRs) their roles would indeed change so that the arrow of time would change.

The outcome of BSFR is a superposition of space-time surfaces leading to the 3-surface in the final state. BSFR looks like deterministic time evolution leading to the final state [L7] as observed by Minev *et al* [L7].

7. h_{eff} hierarchy [K2, K3, K4, K5] implied by the number theoretic vision [L12, L13] makes possible quantum coherence in arbitrarily long length scales at the magnetic bodies (MBs) carrying $h_{eff} > h$ phases of ordinary matter. ZEO forces the quantum world to look classical for an observer with an opposite arrow of time. Therefore the question about the scale in which the quantum world transforms to classical, becomes obsolete.

8. Change of the arrow of time changes also the thermodynamic arrow of time. A lot of evidence for this in biology. Provides also a mechanism of self-organization [L9]: dissipation with reversed arrow of time looks like self-organization [L29].

3.3.2 "Small" SFRs

"Small" SSRs (SSFRs) are counterparts for "weak" measurements and the arrow of time is not changed in them. Each SSFR is preceeded by a time evolution, which corresponds to a scaling of the causal diamond of the CD acting unitarily on the zero energy state and affecting only its "active" part in its decomposition to a pair of 3-D states, which are called active *resp.* passive depending on whether the part is affect by the unitary evolution or not. Passive boundary of CD and states at it do not change in SSFRs and this corresponds to Zeno effect. In TGD inspired theory of consciousness SSFRs correspond to ordinary consciousness and sensory perceptions and reactions them.

The scalings of the CD, and therefore of future directed light-cones, correspond to the scaling of the light-cone proper time a. The simplest simplifying assumption is that the scalings correspond to powers Λ^n of a fixed scaling $\Lambda : a \rightarrow \lambda a$. In $a_{n-1} \rightarrow a_n = \lambda_{n-1} a_0$, the increment of $\Delta a_n = a_n - a_{n-1} = (\lambda - 1)\lambda^{n-1} a_0$ increases like λ^n. Hence the density of SSFRs with respect to time a decreases rapidly. If SSFR is interpreted as an analog of sensory percept and motor reaction of a consciousness conscious system, the system would become increasingly sluggish and non-reactive. This kind of increasing sluggishness is a characteristic feature of spin glass relaxation processes.

ZEO suggests that exponential decay is replaced with a decay based on power law and that the evolution by SSFRs is analogous to aging in the sense that the reaction of the system become slow. Note that the aging could also correspond to thermalization of MB so that its entropy increases and causes slowing down.

3.3.3 "Big" SFRs

Details of BSFR are not completely fixed. One can consider two options. Both options must satisfy the condition that the states at passive boundary of CD identified as superpositions of 3-surfaces remain invariant during the sequence of SSFRs. The tangent space-to the space-time surfaces need not however remain invariant. Therefore the classical energies of space-time surfaces can change since the energy densities are proportional to time derivatives of embedding space coordinates.

1. The size of CD increases steadily as was the original proposal and is thus not reduce in BSFRs. The problem with the steady increase seems to be that the size of CD becomes infinite eventually and the state evolves to what looks like cosmology. If the energy assignable with zero energy state is conserved, the energy density of matter inside CD increasing without limit becomes arbitrarily small. Is this a catastrophe?

   For TGD inspired cosmology this is the case at the limit of big bang in the sense that the energy density goes like $1/a^2$ (cosmic string dominance) and energy in a co-moving volume vanishes like a, where a is light-cone proper time. One can think that CD defines only perceptive field and that space-time surfaces continue also outside CD up to the maximal size of CD in the hierarchy of selves involved. The zero energy state would have finite energy energy but density of energy would go to zero at the boundary of CD. The perceptive field of conscious entity would increase steadily in size.

   As found, energy need not be conserved in the subsequence SSFRs because Gaussian wave packets of CDs around given size are required so that eigenstates of energy are not in question and the reduction of the width of Gaussian in the sequence of SSFRs implies reduction of average energy. Only the superpositions of 3-surfaces at the passive boundary of CD would be conserved.

Even the conservation of energy combined with the increase of CD need not be a catastrophe. In matter dominated cosmology the conservation of mass takes place with respect to cosmological time which corresponds to the proper time measured as temporal distance from the passive tip of CD. This cosmological mass is not energy but closely relates to it. What looks of course counter-intuitive is that every self would evolve to a cosmology.

2. The size of CD could be also reduced in BFSR [L8]. M^8-H duality and existence of "braney" solutions encourages to take this option serious. The 6-D brane like entities correspond to $t = constant$ sections for linear M^4 time t. They would represent special moments in the life of self. The exceptional 6-D roots of octonionic polynomials as branes would emerge to the perceptive field conscious entity at these moment. Discontinuity of classical space-time evolution as SSFR. Every time-reversed re-incarnation of self would have have "childhood" and experience increase of CD from some minimal size to maximal size.

   Since the size of CD can be reduced, it could happen that the CD remains stuck below certain maximal size for ever. The associated mental images would continue living in the geometric past of bigger CD associated with self. The sub-CDs in past would represent memories of self. Cosmos in 4-D sense would be full of life. The interpretation of CD as perceptive field allows this. CD could also increase and become even a cosmology! This picture looks attractive from the view point of consciousness.

The conjecture is that BSFRs correspond to a time evolution by time translations and gives rise to exponential decay rates whereas SSFRs corresponds to time evolution by scalings and gives rise to power laws for decays.

4 Basic TGD inspired ideas about spin glasses

The basic ideas behind the TGD inspired model of spin glass as a quantum critical system are briefly summarized in the introduction. In this section a more detailed picture is represented.

4.1 What does make the spin glasses so exceptional?

At the level of $H = M^4 \times CP_2$ flux tube picture is expected to provide a realization of a single space-time surface modeled by J_{ij} in the models of spin glass. At the level of M^8, analogous to momentum space, one has electrons with spin and momentum and also dark electrons with $h_{eff} > h$. At the level of H, $h_{eff}/h_0 = n$ corresponds as the dimension of extension of rationals corresponds topologically to a multi-sheeted character reflecting the same feature at the level of M^8.

At the level of $H = M^4 \times CP_2$, the classical fields associated with the flux tubes are important and would serve as a correlate for a distribution of dynamical couplings J_{ij} assignable to spin-spin couplings of spin pairs. J_{ij} could be seen as a model for the space-time surface as a kind of flux tube spaghetti.

Monopole flux tubes are something new in that the magnetic field requires no electric current: the reason is that the cross section is a closed 2-surface carrying quantized monopole flux. Monopole flux tubes could however have a counterpart in the standard description of magnetization based on electron spins: spin is indeed angular momentum without rotational motion (electric current).

$M^8 - H$ duality would suggest that monopole flux tubes could be seen as a space-time correlate at the level of H for the magnetization due to electron spins at the level of M^8. This duality of descriptions would apply to both ordinary electrons with $h_{eff} = h$ and dark electrons with $h_{eff} > h$. What the genuinely new element could be?

1. In the TGD based model for high Tc superconductivity [L19], dark Cooper pairs with members at antiparallel or parallel flux tubes play a key role. If flux tubes are antiparallel, one has spin $s = 0$ Cooper pairs by the flux tube ferromagnetism. If they are parallel, one has

$s = 1$ Cooper pairs. In the recent case $s = 1$ Cooper pairs are suggestive as an explanation of the susceptibility in the NFC case. The directions of flux tube pairs would be random in absence of H but would tend to parallelize in the presence of H.

$s = 0$ pairs assignable to antiparallel flux tubes could appear at T_{g1} and would not contribute to M. This is true if the flux tubes above T_g are small (small h_{eff}) so that spins parallel to the magnetic field of the flux tubed necessarily sum up to zero.

2. Dark Cooper pairs are Galois confined bound states [L26, L25] such that the binding energy compensates for the increase of dark electron energy due the increase of h_{eff}. At quantum criticality these energies would compensate each other making the system extremely sensitive to the fluctuations of the density of the dark pairs. One might even say that the dark pairs provide spin glass with a sensory system. As a matter of fact, in the TGD based model of living matter [L29] this would be the case.

   This could be the essentially new element explaining their complexity and unexpected features such as aging, rejuvenation, memory and even primitive learning, bringing in mind living matter.

Some spin glasses such as $CdCr_{2x}In_{2(1-x)}$ S_4 make a transition to ferromagnetism when the doping ratio r exceeds a critical value near unity. How should one interpret this? As r increases, the density of both electrons and possibly also of Cooper pairs increases. The average distance d between dark electrons of the Cooper pair corresponds to that for monopole flux tubes. It d is proportional to h_{eff}, the value of h_{eff} must decrease. At temperature T_{max} corresponding to the maximal doping ratio, Cooper pairs become unstable and ordinary ferromagnetism is established.

4.2 Discussion of the basic findings

In this section the basic findings about spin glasses are discussed and their possible TGD based explanations are considered.

4.2.1 Empirical support for the presence of monopole flux tubes carrying dark Cooper pairs

The magnetization of spin glass produced by FC decays gradually to what is called remanence magnetization. What is not understood is why the the sum of the remanence and the magnetization produced in NFC equals to the magnetization produced in FC (`https://cutt.ly/VT42brC`). Furthermore, the rate for the decay of FC magnetization is the same as that for NFC magnetization. The TGD picture suggests a natural explanation for this finding. The magnetization is a sum of ordinary, constant ferro-magnetization and of dark magnetization due to quantum critical dark Cooper pairs.

Does NFC correspond to a re-orientation of spins or of flux tube pairs or of both as $M^8 - H$ duality suggests?

1. The classical TGD based model is based on monopole flux tubes. After NFC the spins are oriented parallel to the flux tubes but the flux tubes are oriented randomly and there is no net magnetization. External magnetic field H produces a net magnetization by re-orienting the flux tubes. The part of the magnetization produced by the parallelization of the dark monopole flux tubes would decay to zero for both FC and NFC whereas the ordinary thermally stable ferromagnetic part also produced in FC would correspond to the observed remnant magnetization.

   Do the flux tube magnetic field and that associated with electron spins sum up or do they represent one and the same thing?

2. $M^8 - H$ duality suggests that at the level of M^8, the situation can be described in terms of electron spins alone. In FC, monopole flux tube magnetization would correspond to the spin magnetization of electrons and of dark $s = 1$ electron Cooper pairs. The remnant magnetization would correspond to ferromagnetism due to ordinary electrons whereas dark Cooper pairs gradually decay so that only remnant magnetization assignable to ordinary electrons remains in FC.

3. These two descriptions would be related by M^8-H duality. Parallel monopole flux tube pairs, or equivalently quantum critical dark Cooper pairs, would be responsible for the susceptibility in the phase created by NFC.

Above T_{g1} one would have paramagnetism and only ordinary spins. In the range (T_g, T_{g1}), one would have paramagnetism and $s = 0$ Cooper pairs assignable with the antiparallel edges of rather small closed flux tubes having a shape of square.

4.2.2 The dependence of the magnetization of the cooling procedure

ZFC and FC give different M/H ratio below the transition point T_g. FC produces larger susceptibility, which remains essentially constant below T_g. As the temperature decreases, M decreases in ZFC but remains almost constant in FC. Why should the decrease of T reduce the susceptibility? One would naively expect just the opposite.

Suppose that spin glass is a spaghetti of flux tubes which behave like linear ferromagnets in the sense that spins tend to be parallel to the flux tubes. The spaghetti could be very loose or tight: in the TGD based model for blackhole-like entities the flux tubes fill the entire volume.

1. The external magnetic field H tends to turn the magnetization direction of spins at the flux tubes parallel to itself. It would do the same also for the flux tubes.

   This suggests that in FC the transition is analogous to ferromagnetization making both spins and flux tubes parallel to itself.

2. In NFC, the spins are not magnetized parallel to H but they could be parallelized by the magnetic fields of the flux tubes like in ferromagnets. At T_g the flux tubes tend to be parallel: this would be analogous to spontaneous magnetization: this requires rather large value of h_{eff} to make cyclotron energy scale larger than the thermal energy so that one would have dark ferromagnetism.

   This would however suggest that M increases for $T < T_g$: this is not the case. One can consider two explanations reflecting the duality between description using flux tubes and dark Cooper pairs.

   (a) Could T_g correspond to even quantum criticality at the level of magnetic body (MB), inducing long range quantum fluctuations and correlations due to the dark electrons assignable to long magnetic flux tubes with length proportional to h_{eff}. If this is the case, the length of flux tubes would be longest at T_g. Could this explain why magnetization has a maximum at T_g? One can also argue that quantum criticality makes the system maximally sensitive so that magnetization has a peak.

   (b) Or could the density of dark $s = 1$ Cooper pairs determined by a temperature dependent dynamical equilibrium decrease with T below T_g so that magnetization would depend on T?

3. In the many-sheeted space-time, one can also imagine that the return flux arrives along a different space-time sheet as a much wider flux tube with much weaker magnetic field (by flux conservation). If the flux tubes have the same direction at a given space-time sheet this leads to an analog of spontaneous magnetization. It is however not clear why the magnetization in NFC should decrease below T_g.

4.2.3 Why does the susceptibility decrease below T_g in the NFC case?

In the NFC case, the susceptibility is reduced below T_g. In paramagnetism it is expected to increase and to stay constant in ferromagnetism. How can one understand this? One can imagine two different but equivalent pictures for understanding the susceptibility caused by an external magnetic field H in the NFC case.

1. Monopole flux tubes provide a classical description of magnetization. A given flux tube carries a monopole magnetic flux in absence of currents and has a closed 2-surface as cross section. Monopole flux tubes contribute to the magnetization by orienting parallel to the external field H.

2. One can also think that dark electrons inside the flux tubes have spins parallel to the flux tube: one would have an analog of ferromagnetism at flux tubes. The flux tubes and electron spins would re-orient parallel H. This picture applies also to ordinary magnetization with $h_{eff} = h$.

3. $M^8 - H$ duality suggests that these pictures are equivalent. Dark electron spin magnetization has flux tube magnetization as a classical space-time correlate. Indeed, electron spin magnetization does not involve electron currents since spin does not correspond to a rotating charge.

In the NFC case, one must understand why the susceptibility is reduced rather than increases (paramagnetism) or stays constant (ferromagnetism). Dark electrons cannot appear as free particles but must form bound states by Galois confinement: this mechanism is behind the formation of also Cooper pairs.

1. The Galois bound states of dark electrons [L26, L25] would be responsible for flux tube magnetization. The orientation of flux tubes parallel to H would cause the macroscopic magnetization. One must understand why the density of dark electrons bound states is maximum at T_g.

2. The energy of the dark electron increases with h_{eff}. Dark magnetization requires a formation of bound states of electrons with non-vanishing angular momentum, say spin. The simplest option, inspired by high T_c superconductivity, is that spin 1 Cooper pairs with members at parallel flux tubes are formed and cause the dark magnetization.

3. At $T = T_g$, E_B and the energy needed to increase h_{eff} and thermal energy are identical. Below T_g the rate for thermal excitations of dark bound states reduces and the density of bound states of dark electrons is reduced. This induces quantum criticality and very small perturbations can induce a decay or formation of magnetized phase along flux tube pair.

4. There would be a competition between spontaneous decay of dark electron pair phase and its thermal excitation. The density of dark electron pairs decreases below T_g so that magnetic susceptibility is reduced rather than increasing as in paramagnetism or staying constant as in ferromagnetism.

4.2.4 Some simple quantitative estimates

Some estimates concerning the strength of spin-spin interactions are in order.

1. The spin-spin interaction energy for a pair of electrons is of order $E \sim \alpha/m_e^2 r^3$. For $r = a = 10^{-10}$ m, this gives $E \sim .1$ eV. For $r = 1$ nm, one has $E \sim 10^{-4}$ eV, which corresponds to 1 K. $h_{eff} > h$ would scale up the interaction energy of dark electrons by h_{eff}/h factor.

   Magnetic fields B in the range $10 - 100$ Gauss produce magnetization in spin glasses. For ordinary electrons, the spin interaction energy with B would be in the range $3 \times (10^{-5} - 10^{-4})$ eV and much smaller than spin-spin interaction energy for $h_{eff} = h$ and also much smaller than thermal energy at temperatures in the range 1-100 K. $h_{eff} > h$ is suggestive.

2. Does it make sense to assume that the degrees of freedom for the dark electron spins associated with the flux tubes are frozen in the transition at T_g creating the dark electrons or possibly increasing the value of h_{eff} from them? The freezing should be caused by the magnetic field of the monopole flux tubes. This happens if the cyclotron energy E_c exceeds the thermal energy $E_{th} \sim T$ so that one would have an analog of ferromagnetism.

The cyclotron energy of the dark electron inside the monopole flux tube is $E_c = \hbar_{eff}eB/m$, where B is the magnetic field in the tube. The first guess is that B has the same order of magnitude as the field H inducing the magnetization by the re-orientation of the flux tubes. H has strength in the range $10-100$ Gauss.

E_{th} is in the range $10^{-4}-10^{-2}$ eV at the temperature range 1-100 K and dramatically larger than the cyclotron energy $E_c \sim 10^{-8}-10^{-7}$ eV of electron in a magnetic field of order 10-100 Gauss typically used in FC. For $H010$ Gauss h_{eff}/h for dark electrons should be in the range 10^4-10^6 in order to obtain thermally stable dark magnetization.

4.2.5 Why two critical temperatures?

The transition to spin glass phase involves two critical temperatures T_g and T_{g1} as also the transition to high Tc superconductivity. Consider the general picture first.

1. Flux tubes are in a central role and the string tension assignable to flux tubes depends on the p-adic length scale L_p, $p \simeq 2^k$. Also large values of h_{eff} would be present and increase the otherwise extremely low value of the cyclotron energy above thermal energy and make spontaneous magnetization at "endogenous" magnetic flux tubes possible.

2. In ZEO [L11, L26], the p-adic length scale L_p would naturally determine the size scale of the causal diamond (CD) and $p \simeq 2^k$ (by p-adic length scale hypothesis) would not correlate with h_{eff} and therefore with the dimension of extension of rationals. Only h_{eff} and thus the dark scales associated with MB would fluctuate at quantum criticality and explain the long range correlations involved with it. The distribution of p-adic length scales would not fluctuate at T_g.

One should understand the broad maximum of heat capacity at $T_{g1} > T_g$ in this picture. Why not a single sharp peak? There is no maximum of specific at T_g. Why? Could one answer these questions in the proposed picture?

1. The TGD inspired model for aging in living matter [L30] relies on the assumption that flux tubes as string like entities having an infinite number of geometric degrees of freedom have a limiting temperature, known as Hagedorn temperature T_H, which would be around the physiological temperature about 36-37 C in living matter.

   The existence of limiting temperature implies that specific heat c increases as T_H is approached from below. The increase of the p-adic length scale assignable to the flux tubes at T_{g1} would imply the reduction of the string tension and therefore of T_H and increase c below T_{g1}. This suggests a peak in c. One has however a broad maximum.

2. In spin glass phase, one has a probability distribution $P(\{J_{ij}\})$, and one can think that each choice of $\{J_{ij}\}$ of them corresponds to its own critical temperature. If the hierarchical structure of the energy landscape corresponds to a hierarchy of scales for flux tubes, the critical temperature T_{g1} and also T_g could be replaced with an interval of critical temperatures such that each gives a peak. The net result would be a broad maximum around T_{g1} instead of a peak.

3. That there is no maximum of c at T_g suggests that there is no change in the distribution of the p-adic length scales (of string tensions of flux tubes) that would imply emergence of new T_H and peak in c. Quantum criticality however implies the presence of long dark flux tubes with lengths scaled by h_{eff}/h_0. This would explain the large peak of susceptibility at T_g. Quantum criticality would make the system highly sensitive to external magnetic fields.

4. If T_H decreases at T_{g1}, the string tension of flux tubes must decrease. B should weaken and therefore also the magnetic energy density of the flux tube would weaken. Cyclotron energy E_c is proportional to $\hbar_{eff}eB/m$. Note that if the value of E_c does not change, the two changes due to decrease of B and increase of h_{eff} would compensate for each other.

In high Tc superconductivity Cooper pairs emerge already at $T_{c1} > T_c$. A possible explanation is that dark Cooper pairs associated with closed flux tubes with a shape of flattened square are in question. The flux tubes would however be so short that no macroscopic superconductivity is possible. At $T = T_c$ flux tubes would reconnect to much longer flux tubes and super-conductivity would become possible. Could something similar take place also in spin glasses. Now flux tubes should have the shape of a non-flattened square and their size would scale up as the value of h_{eff} would increase at T_g so that a magnetization by parallelization would become possible.

What about the geometrodynamics of the flux tubes? If the geometric shapes of the flux tubes in the "flux tube spaghetti" depend on time, also the couplings between spins at different flux tubes depend on time. Here the arrangement of flux tubes to form parallel structures could cause the freezing somewhat like the freezing of spins in spontaneous magnetization.

4.3 The relaxation dynamics of spin glasses from the TGD point of view

The relaxation dynamics of magnetization provides information about the dynamics of spin glasses in long time scales.

Consider a system cooled by NFC and subjected for a time interval t_w after the cooling has stopped to a magnetic field H. What happens that M starts to increase and approaches the value M_{FC} emerging during FC.

ZEO inspires the question of what happens when magnetic field H is turned on. If this happens instantaneously, it might induce BSFR and thus time reversal at the level of MB. Does the arrow of time at MB changes permanently by a BSFR localizable to geometric future or does it occur practically at the same time as H is turned on?

The model for the rejuvenation and memory requires that the second BSFR implying original time direction occurs essentially without time lapse. This suggests that the situation could be the same now. Therefore one must understand the increase of M in terms of standard physics. Indeed, if the magnetization of flux tubes takes place the magnetization increases to its FC value. Also the FC can be understood by assuming an ordinary arrow of time during the process. The essential element is the presence of both flux tubes and spins contributing to the observed magnetization.

The parallization of randomly oriented dark flux tubes involving dark Cooper pair condensed would explain the relaxation to M_{FC} in NFC case and randomization of orientations would explain the decay of M_{FC} in FC case to remanent magnetization due to ordinary electrons. The density of dark electron pairs would be gradually reduced as their condensate would be formed.

The relaxation dynamics of spin glasses differs from the naive expectations.

1. The relaxation slows down as t_w increases? Does something happen to the spin glass changing it somehow or is something totally different involved?

2. The relaxation is not exponential but obeys scaling and power law in a reasonable approximation as if the natural time coordinate were a logarithm of the ordinary Minkowski time.

   This suggests that the dynamics of spin glass during relaxation corresponds to a sequence of scalings instead of time translations. In ZEO, SSFRs correspond to scalings and BSFRs to time translations. The power law would correspond to "subjective" time evolution by SSFRs and exponential decay to BSFRs.

3. The time t_w at which H is coupled on or off corresponds naturally to the time zero in the dynamics based on a sequence of unitary scalings. In ZEO this is the case if the appearance or disappearance of H corresponds to BSFR.

Spin glass relaxation exhibits also a phenomenon of aging and rejuvenation under stress. These features can be understood qualitatively in zero energy ontology (ZEO) [K12] [L11].

4.4 Aging, rejuvenation and memory for spin glasses

The aging and rejuvenation of spin glasses seem to have a natural explanation in terms of ZEO. ZEO predicts two kinds of state function reductions (SFRs): "small" SFRs (SSFRs) and "big" SFRs (BSFRs). SSFRs could correspond to aging and rejuvenation could correspond to BSFRs.

4.4.1 Aging of spin glasses and SSFRs

In the case of spin glass experiment, the SSFR as a reaction would correspond to a response to an external DC or AC magnetic field H. Magnetization is the reaction of the spin glass and could correspond to SSFR. The reaction would also involve BSFRs at the lower levels of the self-hierarchy corresponding to that for CDs associated with the system.

A brief summary of relaxation dynamics can be found in the article "Aging, rejuvenation and memory: the example of spin glasses" of Eric Vincent [D2] (`https://cutt.ly/vYq1egY`).

There are several kinds of experiments.

1. One can cool the system in the presence of magnetic field H (this is called field cooling (FC)), stop FC but keep the field on for the time t_w. The magnetization M of the system decays after this. What is found that the drop of magnetization during t_w increases with t_w and that the shape of the magnetization $(M/H)(t,t_w)$ as a function of (t,t_w) depends on t_w.

   The relaxation does not correspond to an exponential decay $exp(-t)$ independently of t_w but becomes slower with increasing t_w. A good fit is obtained using a power function of t/t_w so that scaling invariance seems to be a reasonable approximation.

   One could say that the presence of an external field makes the reactions of the spin glass slower for both DC and AC perturbations. One could perhaps say that the system ages during the period t_w. Also the subsequent relaxation could be interpreted in terms of aging.

2. One can also use NFC, cooling without magnetic field H. Susceptibility as the ratio M/H in the NFC case is much smaller in the final temperature $T_f < T_g$ than in FC, for which it stays almost constant below T_g. One can wait for time t_w after the cooling has stopped and then put the magnetizing field H on and look what happens. It has been found that the development of magnetization depends on t_w and the situation looks very similar to that in the previous case.

3. One can also study AC perturbations of the system and look how relaxation of M/H takes place. Also now one one finds that the reactions depend on both t and t_w and scaling law is suggestive. What is remarkable is that the reaction is noticeably delayed.

   The delay could be perhaps understood in terms of increasing reaction time due to the lengthening of $\Delta a_n \propto \lambda^n$ if a single step in evolution corresponds to constant scaling $a \rightarrow \lambda a$.

4. Also spontaneous fluctuations are studied but will not be discussed in here.

In a reasonable approximation, scaling hypothesis holds true in AC and DC cases that is M/H depends on t/t_w only: as if the proper time coordinate with respect to which time translations are natural, would be $u = log(t/t_w)$. t naturally generalizes to the Lorentz invariant proper time a for either half-cone of cd, defining the time coordinate of rest system.

In ZEO, quantum coherence is possible in arbitrarily long scales by h_{eff} hierarchy and quantum description would be natural. Quantum time evolution operator would correspond to a scaling rather than translation with respect to Minkowski time. This conforms with the proposal that ZEO and SSFRs provide a natural description of the situation.

The dynamics has several time scales with a lower bound at $\sim 10^{-12}$ seconds, which corresponds to the length scale 10^{-4} m. The upper bound exceeds the durations of the experiments. Could these scales correspond to powers of λ defining in the simplified model basic scaling. p-Adic length scale hypothesis suggests that the length scales correspond to powers of $\lambda = p^k$, p a small prime. $p = 2$ appears in the standard form of p-adic length scale hypothesis but there is support also for $p = 3$.

4.4.2 An alternative mechanism of aging

The thermalization of the magnetic body (MB) occurring in the geometric degrees of freedom of the flux tubes causing increasing fluctuations in their shape provides an alternative mechanism of aging as a generation of entropy. This mechanism is proposed as an explanation of biological aging at DNA level [L30]: the thermalization of the geometric degrees of freedom of MB would gradually weaken the control of ordinary matter, in particular DNA, by MB. This thermalization would take place for the scaling operator L_0 and could correspond to an analog of the p-adic thermodynamics used to calculate elementary particle masses. p-Adic thermodynamics leads also to a proposal allowing to get rid of the replica trick.

If the magnetization after NFC is due to re-orientation of the flux tubes parallel to H, the relaxation of M would be naturally to the loss of the orientational order. Could this be caused by the increase of the temperature at flux tubes approaching T_H. In this case, the dark flux tubes would slowly approach thermal equilibrium with the ordinary matter. Could the possible dual description in terms of dark electrons correspond to the reduction of the density of $s = 1$ dark Cooper pairs and possible transformation to $s = 0$ pairs assignable to small thermally generated loops as in the model for aging of DNA as generation of loops spoiling DNA function [L30]?

4.4.3 Memory and rejuvenation

The rejuvenation in the volume relaxation of epoxy glass subjected to a mechanical stress shows a sudden increase of the volume as a reaction: see Fig. 2.14 of [D2] (`https://cutt.ly/vYq1egY`).

A similar effect occurs in the relaxation of χ" when a field H is introduced or temperature is lowered [D2]: see Fig. 2.15 of [D2] (`https://cutt.ly/vYq1egY`). This is a rather dramatic effect difficult to understand in the standard physics framework.

1. During the relaxation process for χ" spin glass temperature is reduced by ΔT and returned back to its initial value. This process is known as negative temperature cycle. As a consequence, the relaxation process seems to restart from some earlier moment of time. A sudden increase of M/H to an earlier value takes place and subsequent development seems to be as before.

2. When the temperature returns to its earlier value after some period τ , the subsystem continues relaxation from the situation in which it was before the perturbation.

The first TGD inspired guess about what might happen relies on quantum criticality.

1. By quantum criticality of dark electron pairs, the sudden change induces a shock effect. This is analogous to what happens when an animal perceives something scary. The animal becomes extremely alert. In the case of "scared" spin glass, this means that the density of dark electrons associated with the monopole flux tues increases and causes an instantaneous increase in M.

2. Also when the situation becomes normal again, shock occurs but the effect of the shock is to bring the density of dark electrons back to its original value and the system continues where it was before the perturbation started. The troublesome question is why the density of dark electrons should return to its original value. Why should it depend on T only if this is not the case after the transition $T \rightarrow T - \Delta T$.

As already noticed, the dependence of relaxation on t/t_w can be understood if BSFR occurs when the perturbation begins or ends suddenly at t_w. Hence one can look at the situation also from the perspective of ZEO.

ZEO predicts that the arrow of time changes in ordinary ("big") state function reductions (BSFRs). TGD inspired consciousness forces to consider a detailed view about how subjective memories are realized and what happens to memories in BSFR.

1. The most plausible, albeit rather strange looking, proposal is that the geometric correlate for the subject moment "Now" corresponds to the hyperplane at which upper and lower half-cones of CD are glued. The memory mental images would be generated at this plane and drift to the geometric future as CD increases in size SSFR by SSFR.

2. In BSFR the active boundary of CD would be fixed and CD would decrease in size meaning that the lower boundary would shift to the direction of future. This would delete the latest memories for some time interval. One might say the reincarnated self experiences "childhood" and the often unpleasant (at least in the case of many living organisms) memories

from the latest period of previous life are deleted. The reincarnated self with reversed time direction starts from a pure table, one might say.

3. What happens during the dream state also suggests that the CD representing CD drifts towards the future as the large CD containing it expands. The assumption is that the evolution of CDs by SSFRs involve scalings. If the scalings sare same for all CDs inside a given large CD, this would be the case. For large CDs, the same scaling would however mean an exponentially larger change of the size than for small CDs.

Suppose that BSFR occurs as a sudden stress or change of temperature is suddenly applied to the spin glass.

1. Memories from the nearest past would be deleted as CD decreases in size in the first BSFR. The active boundary of CD becomes fixed and the MB of spin glass starts life in a reversed time direction as a sequence of SSFRs.

2. The model for the sleep period suggests that CD as the perceptive field of the MB of spin glass follows the system in its path through geometric time by drifting during the reversed time evolution from t_1 to t_2. This is also proposed as an explanation for after images appearing periodically with the disappearance of after image interpreted as time reversed evolution at the level of M, which is not conscious to us.

   This would predict that the system indeed restarts its time evolution by SSFRs, where it was before the first BSFR.

The ZEO proposal could be tested by modifying the negative temperature cycle by allowing values of the final temperature T_f different from the initial value T_i: one would have $T_i \to T_i - \Delta T \to T_f$. The ZEO model predicts that the final state is the state just before t_1. On the other hand, if the state after t_2 is determined by T_f it would not be the same as the state before t_1.

If the interpretation in terms of quantum criticality is correct, the size scale and shape of the closed monopole flux tubes matters.

1. The first guess is suggested by the model of high Tc superconductivity based on antiferromagnetism (now one has paramagnetism). The flux tubes would look like highly flattened squares so that the magnetizations for the sides of the square are of opposite sign.

   Long closed flux tubes with a shape of flattened square could be formed by a reconnection process for shorter flux tubes. For the parallel portions of a highly flattened flux tube magnetizations caused by the flux tube field would have opposite directions, the pair would behave like a long quadrupole and one could not speak of the analog of ferromagnetism.

2. Second option is that the flux tubes at T_g have a shape of square, whose size scale is determined by the value of h_{eff}. By energy minimization, the sides of the squares would tend to be parallel but since the magnetizations at the opposite sides have an opposite sign, frustration is unavoidable in the sale of flux tubes. This option looks rather plausible. Quantum critical long range fluctuations due to the large values of h_{eff} would induce large susceptibility at T_g since the number of parallel flux tubes in a volume with a fixed magnetization direction would increase with h_{eff} and ferromagnetism would dominate.

   Below and above T_g the degree of quantum criticality would be reduced with average value of h_{eff} and the flux tubes would get shorter implying a reduced magnetization. This kind of flux tube could give rise to magnetization in NFC and contribute also in FC besides ordinary spin magnetization.

4.4.4 Memory effects related to the cooling rate

In ordinary glasses the cooling rate has a strong effect on specific volume V and enthalpy H: Fig 3.1 of [D2] (`https://cutt.ly/vYq1egY`) illustrates the situation for epox glass. V and H are larger for a fast cooling than slow one and the relaxation from the final state of a fast cooling to the final state of slow cooling is very slow. Note that also the reezing point from liquid to glass phase also depends on the rate of cooling.

The thermal history affects $(M/H)(T)$ measured by gradually increasing T to T_g. Three thermal histories: fast, slow and stepwise cooling in NFC are compared in Fig. 3.10 of [L30] (`https://cutt.ly/vYq1egY`). A stepwise cooling in NFC induces an oscillation in the development of M/H as temperature is increased. As if the sping class would would remember its cooling history. Even more, associative learning might be involved. The shoulders in the $(M/H)(T)$ curve could correspond to the shoulders in the cooling history.

Could the spin glass system have an associative memory? Does the system associate something that occurred in the change ΔT to the temperature T_n at which the step took place during the cooling? Did the discontinuous steps during the cooling serve as shocks inducing a generation dark electron Cooper pairs, and a "wake-up" of the system. Did the memory of this shock induce a shock as an increase of the dark electron density during the increase of T showing itself as shoulders in the $(M/H)(T)$ curve? Equally well one could ask whether spin glass is a primitive conscious system and this is just what TGD inspired theory of consciousness suggests.

In spin glasses, the cooling rate has no effect on the imaginary (absorbtive) part χ" of the AC susceptibility related to dissipation characterizes delayed reaction whereas the real part χ' is in phase: see Fig 3.2 of (`https://cutt.ly/vYq1egY`). The three situations considered are however very different.

(a) (M/H) (T) curve is obtained by changing the temperature and χ" curve corresponds to a constant T.

(b) H and V do not characterize the response of a system to a perturbation whereas χ", which characterizes a response to an oscillatory perturbation.

Sensitization and habituation are the basic forms of non-associative learning. Could one consider an experiment in which spin glass is repeatedly exposed to a magnetic field H lasting for some duration T. Could habituation as a reduction of the reaction as an effective restart of the M/H relaxation take place.

Could the ZEO based view about memory allow a description for the memory effect and perhaps explain what associative memory could mean at the fundamental level?

(a) Suppose that the addition of an external field after NFC cooling induces BSFR as a shock effect at MB at some level of the hierarchy of conscious entities including also the experimenter. Also the initiation of the cooling procedure could correspond to BSFR and time reversed evolution at some level of hierarchy of CDs and conscious entities involved.

(b) During time evolution potentially conscious subselves representing mental images as memories are stored to the future side of the center hyperplane of CD and the drift to the geometric future as the size of CD increases in SSFRs. The idea that the memories are stored to the geometric future sounds of course weird but seems natural in ZEO. Conscious memories would result by a future directed signal waking these memory mental images as conscious entities.

(c) What happens when the arrow of time changes in BSFR. CD is reduced in size if one assumes that selves have "childhood". The information stored as potential mental images to the geometric future however remains as a kind of silent wisdom of the time reversed self. Silent wisdom because the waking up of these mental images would require signals with an arrow of time opposite to that of time reversed self.

(d) In the recent case, this silent wisdom could represent information about the cooling period. Could it affect the reaction of the spin glass system realized as the $(M/H)(T)$ curve with shoulders and perhaps explain the should as being due to the memories, which associate to the temperatures T_n the temperature increment $-\Delta T$ induce generation of dark Cooper pairs and heightened awareness?

One could imagine that the cooling and heating processes involve an initiating BSFR for some MB at a higher level in the hierarchy of CDs, which in TGD Universe corresponds to a hierarchy of conscious entities with increasing size scales. This includes experimenters.

(a) The BSFR at higher level induces a cascade of BSFRs proceeding downwards in the scale hierarchy like an order of "boss" in some organization.

From the point of view of lower levels, the highest level of the hierarchy determines their "fate" in long time scales and they can affect their fate only in short time scales. There is actually some empirical evidence for this interpretation coming from the experiments of Armor and Sackett [J1] [L31].

(b) The entire cooling procedure - if induced by BSFR - could be seen as "fate" of spin glass. The same interpretation would apply to BSFR inducing the heating back to T_g in presence of magnetic field H.

To what arrow of time for the highest level MB could the increase of T could correspond to?

(a) NFC reduces the temperature by inducing thermal energy transfer from the system. This does not occur spontaneously and requires a conscious agent planning and initializing the process. Also the gradual increase of T to T_g in presence of H fails to occur spontaneously. Both are planned actions. Therefore it is better to leave the question about the arrow of time open: note also that the arrow need not be the same for the levels of the hierarchy.

(b) At the level of the ordinary matter one expects that the real arrow of time is constant for a time interval characterized by the rate of BSFRs: the naive expectation is that it scales like $1/h_{eff}L$, L the size of CD. Higher levels can however force a change of the *effective* arrow of time. Any process, which does not occur "naturally" could correspond to this kind of process.

5 Could the replica trick be replaced by p-adic thermodynamics?

The replica trick introduced by Parisi leads to deep conjectures about the nature of the spin glass energy landscape, and suggests that in the TGD framework ordinary thermodynamics of spin glasses could be replaced by p-adic thermodynamics applied in TGD framework to calculate elementary particle mass squared values as thermal expectations [K7, K1].

5.1 Replica trick

The basic challenge is to calculate the average for the logarithm $F = kTlog(Z)$ of free energy for the partition function used to model spin glass thermodynamically using the distribution for the bond variables $\{J_{ij}\}$. This problem is technically very hard.

(a) Replica trick for the calculation of $log(Z)$ relies on the following formula:

$$log(Z) = lim_{n\to 0}\frac{Z^n - 1}{n} \quad .$$

The problem is that one can only calculate positive powers of Z for n which is integer! One can write $(Z^n - 1)/n = (exp(-nF/kT) - 1)/n$, and if nF/kT is small, one has $(Z^n - 1)/n = -F/kT$. This would however mean that F approaches zero faster than $1/n$ at the limit $n \to \infty$.

(b) The method does not give sensible results without additional assumptions. What is required is called replica symmetry breaking. The failure of ergodicity is the physical motivation for the introduction of the replica symmetry breaking.

Thermal equilibrium is not possible in the entire energy landscape and one must restrict it to a sub-landscape defined by some deep energy minimum. Other minima with the same minimum energy are dropped from consideration. The contributions behind the energy wall surrounding a given minimum are dropped from the partition function.

Replica symmetry breaking is analogous to the trick used for ferromagnets to select the direction of spontaneous magnetization: one does not sum over all directions of spontaneous magnetization. Also in the Higgs mechanism the Higgs vacuum expectation value is a degenerate minimum of energy and action: perturbation theory is performed around the chosen minimum of energy.

Parisi's approach is highly intuitive and its mathematical justification can be challenged. The approach however gives the same results as the competing approaches in the tested cases and is widely applied also to problems not related to spin glasses.

The importance of the approach is that it leads to deep conjectures.

(a) The first conjecture is the hierarchical ordering of the energy landscape.

(b) Second prediction is the ultrametricity of the energy landscape. The distance between two energy valleys is determined by the MiniMax principle. For a given path γ connecting the valleys A and B, the height $h(\gamma)$ of the highest mountain at the path defines the path length: $d(A,B|\gamma) = Max(h(\gamma))$. The path length $Min(d(A,B))$ along the shortest path in this sense is identified as the distance $d(A,B)$ between the valleys A and B. The topology defined by this distance function $d(A,B)$ is ultrametric, which means that it satisfies

$$d(A,B) \leq Max\{d(A,C), d(B,C)\}$$

rather than $d(A,B) \leq d(A,C) + d(B,C)$.

5.2 The hierarchical structure of the energy landscape from the TGD point of view

(a) In the TGD framework this hierarchical ordering would have natural counterparts provided by the many-sheeted space-time characterized by several hierarchies. The extensions of rationals define the most fundamental hierarchy having interpretation as evolutionary hierarchy. This hierarchy is characterized partially by the hierarchy of Planck constants labelling phases of ordinary matter behaving like dark matter. This hierarchy is fundamental in quantum biology inspired by TGD.

(b) The hierarchy of p-adic length scales is a second hierarchy and emerged in p-adic mass calculations using p-adic thermodynamics. It seems that these hierarchies are independent and below this is argued using a simple argument.

What is important is that p-adic topology is ultrametric and in the case of spin glasses this could mean that spin glasses are classified by the value of p-adic prime possibly satisfying p-adic length scale hypothesis $p \simeq 2^k$ emerging in p-adic mass calculations and having interpretation in terms of period doubling.

(c) In quantum TGD, the energy landscape would correspond to the maxima of Kähler function of WCW, which is the action consisting of a volume term and Kähler action K for a preferred extremal identifiable as minimal surface [L28]. If the preferred extremals correspond to minima of this action, one has MiniMax principle and the negative of the Kähler function for the deepest valley could determine $d(A,B)$.

One can ask whether WCW decomposes to sectors labelled by p-adic prime p defining the p-adic length scale and by the value of $h_{eff}/h_0 = n$ as the dimension of extensions of rationals, and whether the topology for the discrete set of maxima of K in WCW (rather than all 3-surfaces) could be p-adic topology.

How is the p-adic prime p determined?

(a) The most general option is that the p-adic length scale hierarchy is independent of the hierarchy of extensions of rationals. The size scale of the CD associated with a particle with mass m is defined as Compton $L = h_{eff}/m$. One can associate to this length scale a p-adic mass scale defined by prime as near as possible to $p \simeq 2^k$. Equivalently, Compton length defines p-adic mass scale.

 p-Adic length scales are defined as $L_p = k\sqrt{p}R$, where R is CP_2 "radius", say the radius assignable to the length $L = 2\pi R$ of geodesic line, and k is a numerical constant. The size scale of M^4 projection of 3-surface at mass shell should correspond to the p-adic mass scale $m_p = \hbar_{eff}/L_p$ for the particle with mass m. By $M^8 - H$ duality mapping mass shells to CDs, the p-adic length scale L_p characterizes the size scale of cd.

(b) It seems that one cannot assign a unique p-adic length scale to a given extension of rationals.

 The roots r_n of P scale like $r_n \to \lambda r_n$ under a rational scaling $o \to \lambda o$ of the octonionic argument of P. The extension of rationals is not affected. The scaling scales the mass spectrum and spectrum of Compton lengths and p-adic length scales. Hence a given extension of rationals gives rise to a spectrum of p-adic length scales so that all p-adic length scales are possible for a given extension of rationals.

(c) Earlier I have also considered the possibility that a given extension of rationals could correspond to several preferred primes, say the ramified primes associated with the extension appearing as prime factors appearing in the product of moduli squared for the roots of the polynomial P with rational coefficients. The above argument does not conform with this idea.

5.3 Could spin glass ultrametricity correspond to p-adic ultrametricity?

p-Adic numbers have different notion of nearness than reals. The numbers x and $x + kp^n$ are near to each other for large enough value of n. Could this notion of nearness make the p-adic counterpart of the energy landscape smooth?

Could p-adic norm replace ultrametric norm? Could one use a variant of p-adic thermodynamics, which for large values of p converges extremely rapidly? This would replace $exp(-E/T)$ with p^{E/T_p}, $T_p = T/log(p)$ such that E/T_p is integer valued. The change of sign comes from the condition that the exponent must approach zero for large integer valued E/T_p.

The existence of the Boltzman weight poses extremely powerful restrictions to the dynamics: energy is quantized as multiples of a basic and and one has $T_p = 1/n$.

The key idea is very simple.

(a) For the p-adic valued partition function, the calculation of $log(Z)$, $Z = 1+X$, $X = O(p)$ is extremely simple. One can expand $log(Z)$ as p-adic power series with respect to X just like ordinary logarith and for large values of p expected also in the recent situation the two lowest terms are enough, just as in mass calculations.

 One could use the p-adic analog of replica trick as

$$log(Z) = lim_{n\to\infty}\frac{Z^{p^n}-1}{p^n} \quad .$$

 Now p^n, $n > 0$, would go to zero in p-adic sense.

(b) This trick is not actually needed at all! A little calculation shows that a direct calculation of $log(Z)$ gives the same result.

 The problems with the replica trick would be due to the wrong topology. What is encouraging is that the ultrametric topology emerges from the replica model!

$log(Z)$ would be mapped to its real counterpart by canonical identification $I : \sum x_n p^n \rightarrow \sum x_n p^{-n}$ after which the analog for the averaging over P_{ij} would be performed using real integration (p-adic definite integral is highly problematic).

5.4 Basic ideas of p-adic thermodynamics

I have applied p-adic thermodynamics to the calculation of particle masses as thermal values for mass squared operator replacing Hamiltonian [K7, K1]. This approach is Lorentz invariant. Energy is replaced with the generator L_0 for conformal scalings proportional to mass squared operators in string model and also in TGD.

p-Adic length scale hypothesis $p \simeq 2^k$, k some integer (not all integers are possible), is an essential part of the calculation and implies the analog of period doubling (also powers of other small primes can be considered and there is evidence for powers of $p = 3$). One can assign to given elementary particle, a p-adic prime characterizing it. Mersenne primes are favoured.

Expansion in powers of p converges extremely rapidly for large primes: for instance, one has Mersenne prime $p = M_{127} = 2^{127} - 1$ in the case of electrons. Calculations produce p-adic mass squared as a p-adic thermal expectation value mapped to real mass squared by canonical identification $I : x = \sum x_n p^n \rightarrow \sum x_n p^{-n}$. Number theoretic constraints quantize the mass scale.

5.5 Can time evolution of spin glass correspond to scaling?

Is the thermodynamics for conformal weights acceptable in the case of spin glasses or shoud one formulate p-adic thermodynamics for energy?

5.5.1 Time evolution as scaling conforms with the basic properties of spin glasses

It seems that the interpretation of time evolution as scaling conforms with the basic properties of spin glasses.

(a) Relaxations exhibit a breaking of time translation invariance. Scaling invariance appears as an approximate t/t_w dependence of relaxation dynamics. In fact, exponential decay seems to be replaced with a power law behavior implied by scalings. Also the reactions of spin glass to perturbation becomes slower during aging.

Could scalings be more appropriate notion than translations from the point of view of spin glass dynamics? Could time scalings correspond to translations for $u/u_0 = log(t/t_0)$ replacing Minkowski time?

As matter of fact, the light-cone proper time a is a natural Lorentz invariant time parameter in TGD framework, $u/u_0 = log(a/a_0)$ defines the analog of time variable.

(b) The discrete sequence $t_n/t_0 = n$ natural for a periodic system defined by energy eigenstate would be replaced by a discrete sequence $u_n/u_0 = n$ and would correspond to a sequence $t_n/t_0 = e^n$. The durations of unitary time evolutions would increase exponentially. Can one interpret this as a slowing down of the quantum dynamics by SSFRs? The times between the reactions of spin glass as SSFRs increase exponentially.

Note that conformal invariance allows the replacement of the complex variable z with $log(z/z_0)$ so that this replacement would be allowed.

(c) In ZEO based quantum theory, "small" state function reductions (SSFRs) as analogs of weak measurements are preceded by unitary evolution for the scaling generator L_0 so that this picture would fit with fundamental TGD. The time evolutions by scaling evolutions followed by SSFRs correspond in TGD subjective time evolution and this would conform with the idea that spin glasses are in some primitive sense living and conscious systems.

5.5.2 p-Adic thermodynamics for the scaling operator interpreted as energy

What would be the interpretation of the scaling operator L_0. Could one interpret it as energy or is the only reasonable interpretation as mass squared?

(a) The assumption that L_0 is proportional to mass squared operator m^2 looks unphysical. One can however wonder whether one could identify energy as a scaling generator. Scaling corresponds to a translation for $u = log(t/t_0)$. If the scaling generator L_0 acts as Hamiltonian, it would do so for $u = log(t)$ rather than t. Time would be run very slowly. Could the very slow dynamics of spin glasses reflect this?

(b) Recall that ordinary 2-D conformal invariance includes scaling symmetry and allows the replacement of complex variable z with $log(z/z_0)$ so that this replacement would be allowed in this framework. Note that this transformation is not global conformal transformation.

Could one formulate p-adic thermodynamics for energy instead of mass squared so that energy would be represented scaling operator L_0?

(a) p-Adic thermodynamics would give $Z_p = Tr(p^{L_0/T_p})$ as a powers series in p. The expansion of Z_p would converge extremaly rapidly so that few lowest terms would be enough. The logarithm of $Z_p = 1 + O(p)$ would exist p-adically and as $log(1 + x)$ and only a few terms would be needed.

(b) This quantity would be mapped to its real counterpart by canonical identification I and would could be integrated over the distribution for flux tubes determing the couplings J_{ij}.

Both mass squared and energy appear as natural observables allowing thermalization if $M^8 - H$ duality is accepted.

(a) At M^8 level the octonionic continuations of polynomials allow as solutions also 6-branes for which the projection to the future light-one is constant energy surface $E = E_n$, which is a root of the polynomial defining the region of 4-surface consider.

This corresponds to a set of discrete rest mass values $m > 0$ with maximum $m = E_n$. For a given mass value in this range, one would have the roots E_n as possible energy values.

(b) Could one consider thermodynamics with p-adic temperature defined by the inverse of p-adic time scale assignable defined by some mass in this range? The allowed energies would correspond to the intersections of the $E = E_n$ hyperplanes with the mass shell considered.

Number theoretical universality stating that the thermodynamics makes sense for p-adic number field defined by the p-adic prime p, poses however a problem.

(a) $exp(E_n/T)$ or its p-adic analog p^{E_n/T_p}, $T_p = Tlog(p)$ is in general a transcendental number since E_n is an algebraic number as a root of the polynomial considered so that numbertheoretic universality would be lost.

(b) Galois confinement saves the situation. The physical states formed at fundamental from quarks are Galois singlets, which means that the components of four-momentum for the bound states are ordinary integers, when periodic boundary conditions for the CD are used and the momentum unit naturally defined by CD is used. For physical states allowed by Galois confinement, the thermodynamics makes sense. Number theoretic conditions allow also multiples of E_n so that thermodynamics makes sense for many-boson systems.

(c) Note that Galois singletness implies that also the mass squared eigenvalues for the physical state in ordinary p-adic thermodynamics are integers for a natural unit.

T_p would relate to T via the formula $T = T_p/log(p)$ and T_p would be quantized as inverse integer.

Some questions remain to be answered.

(a) How does the "conformal free energy" $F_R = T_p log(Z_p))_R$ obtained by canonical identification relate to free energy? Is there any relationship? In p-adic thermodynamics for mass squared, F has dimensions of mass squared whereas mass squared expectation value is analogous to $E \propto (Td/dT)F$. If the considered generalization in the case of energy exists, the interpretation as genuine free energy makes sense.

(b) Is the system characterized by a single p-adic prime or is there a probability distribution over the values of p coming as powers of 2 if p-adic length scale hypothesis is true (period doubling appearing in complex systems serves as an analog).

Could this explain the appearance of several time scales? Or could the spectrum of h_{eff} explain this or do the scalings by powers of λ - perhaps a small prime - give these scales? Could the WCW wave functions over different flux tube configurations correspond to varying p-adic length scales.

5.5.3 Does replica trick have some physical interpretation

The replica trick of Parisi and replica symmetry breaking play a key role in the theory of spin glasses. These notions are however purely formal tricks without any physical interpretation in standard physics framework.

(a) The overlap between spin configurations associated with 2 different replicas is a key notion used to characterize spin glasses. It is essentially the inner product $q_{a,b} = \langle S_a, S_b\rangle = \sum_i s_a(i)s_b(i)/N$ of N-vectors S_a and S_b formed by the spin configurations represented as vectors normalized by the number N of spins and measures how much the spin configurations resemble each other.

The overlap $\langle S_a, S_b >\rangle 1$ between configurations inside the same valley is argued to be constant for the generic configurations and approach $q(a, b) = 1$ at $T \to 0$ limit. This means that the spin configurations are strongly correlated. For configuration associated with different valleys $q(a, b)$ would vanish since there would be no correlation. My understanding is that the value of the overlap inside the same valley orders the valleys hierarchically.

(b) Replica symmetry breaking is introduced as a mathematical trick to select only those configurations, which can be connected thermally. This breaking is analogous to the selection of the ferromagnetic ground state in spontaneous magnetization and also to the Higgs mechanism in which direction of the Higgs field must be specified. Mathematically the replica symmetry breaking is introduced as interactions between the replicas: simplest interactions are bilinear with respect to spins of two replicas assignable with the same site i.

In the framework of standard physics, replicas and replica interactions look like formal tricks. Could they have some physical meaning in the many-sheeted space-time of TGD?

(a) Could different replicas of a spin at a given site i correspond to the orbits of the site of the spin under the Galois group associated with $h_{eff}/h_0 = n$? Could the value $n = h_{eff}/h_0$ as the dimension of extension of rationals and the order of the Galois group correspond to the number n of replicas? Could there be a genuine physical interaction between the spins at the orbit of the Galois group?

(b) Or could the replica trick be seen as an attempt to describe quantum superposition? Could the constant overlap for a given energy valley correspond to a quantum expectation $\langle \sum S_i^2\rangle/N$? In this case, replicas would actually correspond to a quantum superposition of different spin configurations. This would conform with the idea about ferromagnetism at a given flux tube forcing formulated.

(c) Could the hierarchical structure with the levels parametrized by the overlap q reduce to a hierarchy of flux tubes within flux tubes reducing to both h_{eff} hierarchy or p-adic length scale hierarchy? Could the total spins of flux tubes act like super-spins? This would conform with the idea of length scale evolution of the renormalization theory reducing in the TGD framework to a discrete p-adic length scale evolution.

$M^8 - H$ duality [L12, L26] raises the question whether almost replicas could be a universal phenomenon in TGD?

(a) At the level of M^8 polynomial P gives as its roots 3-D complex mass shells with mass squared values given by the roots of P. These provide holographic data giving rise to 4-surface going through the mass shells of the same complexified M^4. The interiors of X^4 going through the mass shells, are determined by maps defined by local $SU(3) \subset G_2$ elements $g(x)$ acting on M^8_c as an octonionic automorphism and deforming M^4. If $U(2) \subset SU(3)$ leaves leaves each image point invariant, this gives $M^8 - H$ duality since the image points correspond to points of CP_2.

The boundary conditions are that g effectively reduces to a unity at mass shells and that the tangent spaces of $X^4 \subset M^8$ are parallel to M^4 at the mass shells. Together with the rationality conditions these conditions are expected to determine the map g highly uniquely in accordance with the Bohr orbit property of the $M^8 - H$ image.

(b) Suppose assigned to a polynomial P a many particle state constructible from quarks (leptons could be bound states of antiquarks). What about the products $\prod P_i$ of irreducible polynomials? They are not irreducible but also define 4-surfaces which are uncorrelated and have discrete points as intersections in the generic case. Associativity of the product however requires that the choice of $M^4 \subset M^8$ is the same for all P_i. Two polynomials P_i have a common mass shell if they have a common root.

One could consider a hierarchy of increasingly complex many-particle states analogous to elementary particles and in which one constructs products $\prod P_i$ and maps the mass shells for P_i to space-time surfaces inside CDs in H such that the CDs associated with P_i can have different cm positions in $M^4 \subset H$. In the geometric sense, the exact replica property would require $P_i = P$ and is therefore not possible. Fermi statistics would not however allow exactly identical multiquark states. Even replica interactions could be obtained by a slight deformation of $\prod P_i$ making it irreducible.

This construction brings into mind the hierarchical construction of infinite primes as a repeated second quantum of arithmetic quantum field theory such that ordinary primes label bosons and fermions at the lowest level [K11].

REFERENCES

Theoretical Physics

[B1] Minev ZK et al. To catch and reverse a quantum jump mid-flight, 2019. Available at: https://arxiv.org/abs/1803.00545.

Condensed Matter Physics

[D1] On the replica approach to glasses, 1997. Available at: https://chimera.roma1.infn.it/P_COMPLEX/pa_1997d.ps.

[D2] Vincent E. Aging, rejuvenation and memory: the example of spin glasses, 2006. Available at: https://arxiv.org/pdf/cond-mat/0603583.pdf.

[D3] Anderson PW Edwards SF. Introduction to the Theory of Spin Glasses. *J. Phys. F*, 5(965), 1975.

[D4] Newman CM Stein D. Spin Glasses: Old and New Complexity, 2012. Available at: https://www.researchgate.net/publication/224959328_Spin_Glasses_Old_and_New_Complexity.

Cosmology and Astro-Physics

[E1] Nottale L Da Rocha D. Gravitational Structure Formation in Scale Relativity, 2003. Available at: https://arxiv.org/abs/astro-ph/0310036.

Fringe Physics

[H1] Reiter ES. Experiment and Theory Removing all that Quantum Photon Wave-particle-Duality Entanglement Nonsense. *Proceedings of the CNPS*, 10, 2017. Available at: https://cutt.ly/rlBgOl1. .

Neuroscience and Consciousness

[J1] Sackett AM Armor DA. Accuracy, error, and bias in predictions for real versus hypothetical events. *J Pers Soc Psychol*, 91(4):583–600, 2006.

Books related to TGD

[K1] Pitkänen M. Construction of elementary particle vacuum functionals. In *p-Adic Physics.* *https://tgdtheory.fi/tgdhtml/Bpadphys.html*. Available at: https://tgdtheory.fi/pdfpool/elvafu.pdf, 2023.

[K2] Pitkänen M. Criticality and dark matter: part I. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/qcritdark1.pdf, 2023.

[K3] Pitkänen M. Criticality and dark matter: part II. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/qcritdark2.pdf, 2023.

[K4] Pitkänen M. Criticality and dark matter: part III. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/qcritdark3.pdf, 2023.

[K5] Pitkänen M. Criticality and dark matter: part IV. In *Dark Matter and TGD:* *https://tgdtheory.fi/tgdhtml/Bdark.html*. Available at: https://tgdtheory.fi/pdfpool/qcritdark4.pdf, 2023.

[K6] Pitkänen M. Dark Matter Hierarchy and Hierarchy of EEGs. In *TGD and EEG: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdeeg1.html*. Available at: https://tgdtheory.fi/pdfpool/eegdark.pdf, 2023.

[K7] Pitkänen M. Massless states and particle massivation. In *p-Adic Physics.* *https://tgdtheory.fi/tgdhtml/Bpadphys.html*. Available at: https://tgdtheory.fi/pdfpool/mless.pdf, 2023.

[K8] Pitkänen M. Quantum gravity, dark matter, and prebiotic evolution. In *Evolution in TGD Universe.* *https://tgdtheory.fi/tgdhtml/Btgdevolution.html*. Available at: https://tgdtheory.fi/pdfpool/hgrprebio.pdf, 2023.

[K9] Pitkänen M. Quantum Model for Nerve Pulse. In *TGD and EEG: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdeeg1.html*. Available at: https://tgdtheory.fi/pdfpool/nervepulse.pdf, 2023.

[K10] Pitkänen M. Recent View about Kähler Geometry and Spin Structure of WCW . In *Quantum Physics as Infinite-Dimensional Geometry.* *https://tgdtheory.fi/tgdhtml/Btgdgeom.html*. Available at: https://tgdtheory.fi/pdfpool/wcwnew.pdf, 2023.

[K11] Pitkänen M. TGD as a Generalized Number Theory: Infinite Primes. In *TGD as a Generalized Number Theory: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdnumber1.html*. Available at: https://tgdtheory.fi/pdfpool/visionc.pdf, 2023.

[K12] Pitkänen M. Zero Energy Ontology. In *Quantum TGD: Part I.* *https://tgdtheory.fi/tgdhtml/Btgdquantum1.html*. Available at: https://tgdtheory.fi/pdfpool/ZEO.pdf, 2023.

Articles about TGD

[L1] Pitkänen M. Cold fusion, low energy nuclear reactions, or dark nuclear synthesis? Available at: https://tgdtheory.fi/public_html/articles/krivit.pdf., 2017.

[L2] Pitkänen M. Does $M^8 - H$ duality reduce classical TGD to octonionic algebraic geometry?: part I. Available at: https://tgdtheory.fi/public_html/articles/ratpoints1.pdf., 2017.

[L3] Pitkänen M. Does $M^8 - H$ duality reduce classical TGD to octonionic algebraic geometry?: part II. Available at: https://tgdtheory.fi/public_html/articles/ratpoints2.pdf., 2017.

[L4] Pitkänen M. Does $M^8 - H$ duality reduce classical TGD to octonionic algebraic geometry?: part III. Available at: https://tgdtheory.fi/public_html/articles/ratpoints3.pdf., 2017.

[L5] Pitkänen M. Philosophy of Adelic Physics. Available at: https://tgdtheory.fi/public_html/articles/adelephysics.pdf., 2017.

[L6] Pitkänen M. Philosophy of Adelic Physics. In *Trends and Mathematical Methods in Interdisciplinary Mathematical Sciences*, pages 241–319. Springer.Available at: https://link.springer.com/chapter/10.1007/978-3-319-55612-3_11, 2017.

[L7] Pitkänen M. Copenhagen interpretation dead: long live ZEO based quantum measurement theory! Available at: https://tgdtheory.fi/public_html/articles/Bohrdead.pdf., 2019.

[L8] Pitkänen M. $M^8 - H$ duality and consciousness. Available at: https://tgdtheory.fi/public_html/articles/M8Hconsc.pdf., 2019.

[L9] Pitkänen M. Quantum self-organization by h_{eff} changing phase transitions. Available at: https://tgdtheory.fi/public_html/articles/heffselforg.pdf., 2019.

[L10] Pitkänen M. Solar Metallicity Problem from TGD Perspective. Available at: https://tgdtheory.fi/public_html/articles/darkcore.pdf., 2019.

[L11] Pitkänen M. Some comments related to Zero Energy Ontology (ZEO). Available at: https://tgdtheory.fi/public_html/articles/zeoquestions.pdf., 2019.

[L12] Pitkänen M. A critical re-examination of $M^8 - H$ duality hypothesis: part I. Available at: https://tgdtheory.fi/public_html/articles/M8H1.pdf., 2020.

[L13] Pitkänen M. A critical re-examination of $M^8 - H$ duality hypothesis: part II. Available at: https://tgdtheory.fi/public_html/articles/M8H2.pdf., 2020.

[L14] Pitkänen M. Could quantum randomness have something to do with classical chaos? Available at: https://tgdtheory.fi/public_html/articles/chaostgd.pdf., 2020.

[L15] Pitkänen M. Could TGD provide new solutions to the energy problem? Available at: https://tgdtheory.fi/public_html/articles/proposal.pdf., 2020.

[L16] Pitkänen M. How to compose beautiful music of light in bio-harmony? https://tgdtheory.fi/public_html/articles/bioharmony2020.pdf., 2020.

[L17] Pitkänen M. The dynamics of SSFRs as quantum measurement cascades in the group algebra of Galois group. Available at: https://tgdtheory.fi/public_html/articles/SSFRGalois.pdf., 2020.

[L18] Pitkänen M. About the role of Galois groups in TGD framework. https://tgdtheory.fi/public_html/articles/GaloisTGD.pdf., 2021.

[L19] Pitkänen M. Comparing the Berry phase model of super-conductivity with the TGD based model. https://tgdtheory.fi/public_html/articles/SCBerryTGD.pdf., 2021.

[L20] Pitkänen M. Galois code and genes. https://tgdtheory.fi/public_html/articles/Galoiscode.pdf., 2021.

[L21] Pitkänen M. Is genetic code part of fundamental physics in TGD framework? Available at: https://tgdtheory.fi/public_html/articles/TIH.pdf., 2021.

[L22] Pitkänen M. Is $M^8 - H$ duality consistent with Fourier analysis at the level of $M^4 \times CP_2$? https://tgdtheory.fi/public_html/articles/M8Hperiodic.pdf., 2021.

[L23] Pitkänen M. Negentropy Maximization Principle and Second Law. Available at: https://tgdtheory.fi/public_html/articles/nmpsecondlaw.pdf., 2021.

[L24] Pitkänen M. Some questions concerning zero energy ontology. https://tgdtheory.fi/public_html/articles/zeonew.pdf., 2021.

[L25] Pitkänen M. TGD and Condensed Matter. https://tgdtheory.fi/public_html/articles/TGDcondmatshort.pdf., 2021.

[L26] Pitkänen M. TGD as it is towards the end of 2021. https://tgdtheory.fi/public_html/articles/TGD2021.pdf., 2021.

[L27] Pitkänen M. TGD based interpretation for the strange findings of Eric Reiner. https://tgdtheory.fi/public_html/articles/unquantum.pdf., 2021.

[L28] Pitkänen M. What could 2-D minimal surfaces teach about TGD? https://tgdtheory.fi/public_html/articles/minimal.pdf., 2021.

[L29] Pitkänen M and Rastmanesh R. The based view about dark matter at the level of molecular biology. Available at: https://tgdtheory.fi/public_html/articles/darkchemi.pdf., 2020.

[L30] Pitkänen M and Rastmanesh R. Aging from TGD point of view. https://tgdtheory.fi/public_html/articles/aging.pdf., 2021.

[L31] Pitkänen M and Rastmanesh R. Why the outcome of an event would be more predictable if it is known to occur? https://tgdtheory.fi/public_html/articles/scavhunt.pdf., 2021.