# Spin Glasses, Complexity, and TGD

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## Contents



# 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 manner. 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 $_{ij}\}$. Free energy $F = kTlog(Z(\{_{ij}\})$ 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 $log(Z(\{_{ij}\})$ 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 zero energy ontology (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.

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