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Temperature chaos in the local magnetization of spin glasses ☆

M.C. de Moura, S. Coutinho*

Departamento de Física, Laboratório de Física Teórica Computacional, Universidade Federal de Pernambuco, Cidade Universitária, CEP 50670-901, Recife, Pernambuco, Brazil

Abstract

Several simulations of the Ising spin-glass model on diamond hierarchical lattices with fractal dimensions $d_F = 2, 2.58$ and 3 were performed. By means of an exact recursion procedure the temperature dependent local magnetization is calculated and the distribution of overlaps between configurations with slightly different temperatures is investigated. Both Gaussian and delta-bimodal distributions for the coupling constants were considered. At very low temperatures, evidences of chaotic behavior induced by temperature is found for all cases except for $d_F = 2$ lattice with delta-bimodal distribution.

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Keywords: Spin glass; Temperature chaos; Hierarchical lattices

We investigate the phenomenon of chaos induced by temperature on the local magnetization of the Ising spin-glass model defined on diamond hierarchical lattices with fractal dimensions $d_F = 2, 2.585\ldots$ and 3. Several simulations were performed to investigate the distribution of the overlaps between configurations of the local magnetization of a given sample but with slightly different temperatures T and $T + \delta T$. This problem has been studied by several authors recently, showing contradictory results among them, although the majority of them indicates the presence of temperature chaos [1–7].

We define the temperature dependent overlap as

$$q^{(2)}(T, \delta T) \equiv \left[\frac{1}{N_S} \sum_{i=1}^{N_S} \langle \sigma_i(T) \rangle_J \langle \sigma_i(T + \delta T) \rangle_J \right], \qquad (1)$$

where $[\cdots]$ indicates averaging over the disorder and $\langle \cdots \rangle$ the thermal average. The subscript J means that the local magnetizations $\langle \sigma_i(T) \rangle_J$ of the each configuration were calculated with the same realization of couplings.

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*Corresponding author. Fax: +55-81-32710359.
E-mail address: sergio@lftc.ufpe.br (S. Coutinho).

The local magnetizations $\langle \sigma_i(T) \rangle_J$ were calculated by a method that encompass real space renormalization group decimation and an exact recursion procedure [8].

For each lattice fractal dimension we simulated 10^5 samples for both Gaussian and a delta-bimodal distributions and the temperature ranging from $T = 10^{-5}$ to 1.0 with step 0.2, calculating the ordinary Edwards–Anderson order parameter $q_{EA} = q^{(2)}(T, 0)$ and the $q^{(2)}(T, \delta T)$ with $\delta T = 10^{-3}$. Our analysis is based upon the difference between the undisturbed and the temperature disturbed data. Due to computational limitations we consider lattices with $N = 3$ to $N_{max} = 9$ hierarchies for $d_F = 2$ ($L_{max} \simeq 418$); $N_{max} = 8$ hierarchies for $d_F = 2.585\ldots$ ($L_{max} \simeq 212$) and $N_{max} = 6$ hierarchies for the $d_F = 3$ ($L_{max} \simeq 53$), where L_{max} gives the equivalent size of the corresponding hyper-cubic lattice with N_{max} hierarchies.

To search for temperature chaos we analyze the scaling behavior of temperature overlap deviation $\Delta q = [q(T, 0) - q(T, \delta T)]$. When Δq increases with the increasing size of the lattice the configurations of the spin-glass phase should be very sensitive to temperature changes characterising a *chaotic behavior*. On the contrary, if Δq remains constant or decreases with the increasing lattice size, hence the spin-glass configurations must be robust against temperature variations.

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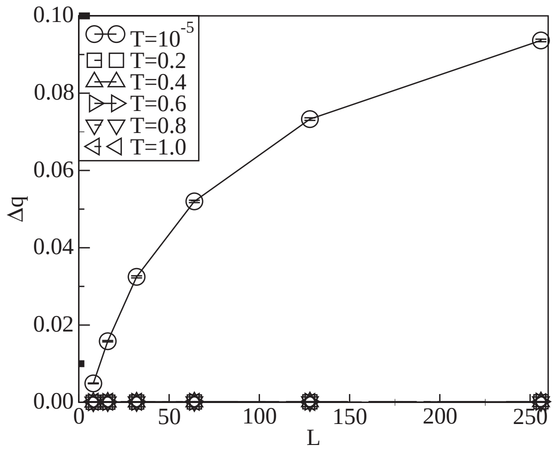

Fig. 1. Temperature overlap deviation for the delta-bimodal distribution and $d_F = 2.585\ldots$ lattice. $\Delta q < 2.0 \times 10^{-4}$ for $T > 0.2$.

For delta-bimodal models chaotic behavior is found to be evident at very low temperatures $T = 10^{-5}$ for lattices with $d_F = 2.585\ldots$ (see Fig. 1) and $d_F = 3$, but being absent for $d_F = 2$ lattices. However, when the Gaussian distribution for the couplings is considered the chaotic behavior is less evident than in the discrete case, although it is present in wide range of temperatures up to $0.4\sim0.6$ for lattices with $d_F = 2.58$ (see Fig. 2) and $d_F = 3$, respectively. For the case $d_F = 2$, chaotic behavior was found only at very low temperature as it should be expected. It is worth to mention that the lower critical dimension for spin glasses is believed to be around $d_l = 2.5$ hence there is no condensed phase in two dimension except for $T = 0$.

Our results indicate that chaos induced by temperature occurs but only at very low temperature, that is, the spin configurations of a given sample at slightly different temperatures should be macroscopically different. Due to the low temperature range this behavior is not accessible by present Monte-Carlo simulations as was the case of the work of Ref. [3].

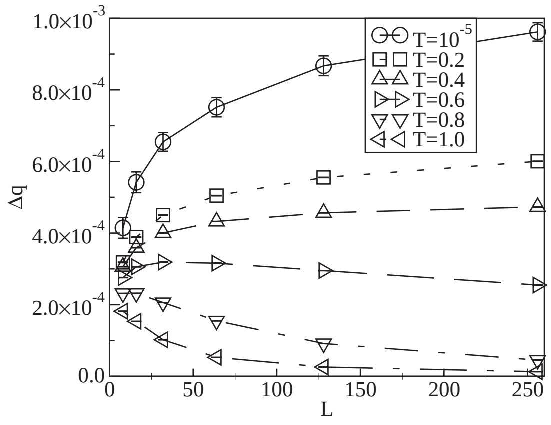

Fig. 2. Temperature overlap deviation for Gaussian distribution and $d_F = 2.585\ldots$ lattice.

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