Quantum spin glasses on the GPU

Víctor Martín-Mayor* and Isidoro Gonzalez-Adalid Pemartin†

Departamento de Física Teórica, Universidad Complutense de Madrid, Madrid 28040, Spain

Masimo Bernaschi‡

Istituto per le Applicazioni del Calcolo CNR,

via dei Taurini 19, 00185 Rome, Italy

Giorgio Parisi§

Dipartimento di Fisica, Sapienza Università di Roma and INFN,

Sezione di Roma 1, I-00185 Rome, Italy

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An Ising Quantum Spin Glass (QSG) is the prototype of disordered systems whose dynamics is affected strongly by quantum effects. It is thus surprising that we lack a clear picture about its phase transition with the transverse field at zero temperature for space dimension D equal to (or larger than) two. In fact, the critical field separates the paramagnetic phase (at large fields), from the spin glass phase (at low fields).

Currently there are two competing theories and we aim at finding out which is the correct one by providing the answer to four important questions in the particular case of D=2: i) What is the value of the quantum-dynamical z exponent?; ii) How should the Finite Size Scaling analysis [2] be carried out when exponent z is unknown? iii) Does exponent z depend on the considered symmetry sector? iv) What are the critical exponents for this universality class [1, 2]? These questions are addressed through a combination of exact diagonalization of the Transfer Matrix [1] (for small system sizes, up to $L = 6$, which helps to control the limit of zero temperature) and Quantum Monte Carlo (which allows us to reach larger values of L). We highlight that a better understanding of the scaling of the spectral gap with respect to the system size, is instrumental in the assessment of the quantum computational complexity of the adiabatic quantum algorithm proposed for some classical optimization problems [3, 4].

Our numerical approach pushes algorithms for Ising quantum spin glasses beyond the present limits and led us to develop two novel, highly tuned, multi GPU codes. CQSG is a Monte Carlo code for Quantum Spin Glass that relies on three levels of parallelism: multi-spin coding, multi (CUDA) threads, and multi-GPU (running simultaneously different values of the transverse field to speed up the dynamics, as required by the Parallel Tempering technique [5]). EDQSG finds the first four eigenvalues (and the eigenvectors corresponding to the first two eigenvalues) of the Transfer Matrix of a 6x6 Ising Quantum Spin Glass by using up to 1024 GPU.

Our data-analysis is largely inspired by the exact diagonalization of smaller systems. In order to avoid any controversial assumption about the quantum dynamical exponent, we effectively reach the limit of zero temperature in our simulations. We find that the spin-glass susceptibility is barely divergent at the critical point, which is recognized as the crucial difficulty hampering previous works. Inspired by [6], we work-out practical alternatives to

* vicmarti@ucm.es

† isidorog@ucm.es

‡ massimo.bernaschi@cnr.it

§ giorgio.parisi@uniroma1.it

study the phase transition.

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