# Beyond-Classical Computation in Quantum Simulation

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I will discuss recent work [1] demonstrating the quantum simulation of critical dynamics beyond the reach of state-of-the-art classical methods, using superconducting quantum annealers. I will also discuss at least two recent works [2,3] that advance the classical state of the art, and how they narrow (but do not close) the parametric range of demonstrated quantum advantage for some lattice geometries.

Quantum computers hold the promise of solving certain problems that lie beyond the reach of conventional computers. Establishing this capability, especially for impactful and meaningful problems, remains a central challenge. Here we show that superconducting quantum annealing processors can rapidly generate samples in close agreement with solutions of the Schrödinger equation. We demonstrate area-law scaling of entanglement in the model quench dynamics of two-, three- and infinite-dimensional spin glasses, supporting the observed stretched-exponential scaling of effort for matrix-product-state approaches. We show that several leading approximate methods based on tensor networks and neural networks cannot achieve the same accuracy as the quantum annealer within a reasonable timeframe. Thus quantum annealers can answer questions of practical importance that may remain out of reach for classical computation.

References

[1] A.D. King et al., Science, 10.1126/science/ado6285
[2] J. Tindall et al., arXiv:2503.05693
[3] L. Mauron and G. Carleo, arXiv:2503.08247

Figures

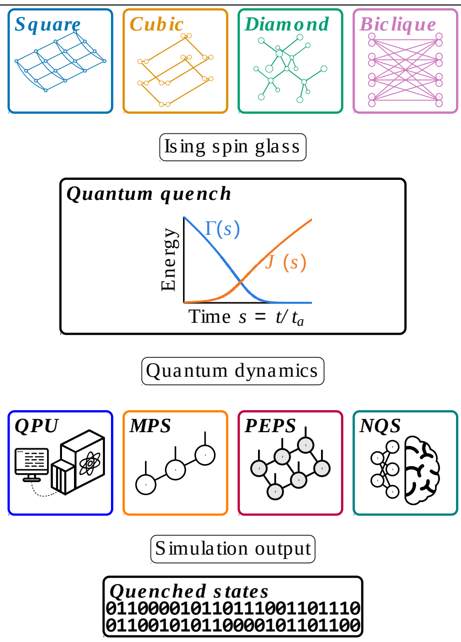


**Figure 1:** Experimental overview. The computational task is to sample from the distribution of output states following an out-of-equilibrium quench through a quantum phase transition separating the paramagnetic and spin-glass phases.

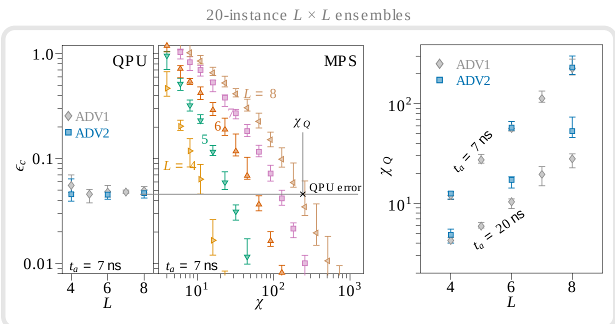


**Figure 2:** MPS requires bond dimension $\chi_Q$, which scales as a stretched exponential in system size, to match QPU quality. This is demonstrated here in a 2D example. When quench time $t_a$ is long, especially for densely connected lattices, correlation length exceeds the reach of alternative methods like PEPS and NQS, leading to simulation regimes that are infeasible with leading classical methods.