Simulating Open Quantum Systems with Molecular Spin Qudits

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Quantum simulation of open quantum systems (QS-OQS), which involves additional units and operations to map environmental degrees of freedom, are strongly constrained by the intrinsic noise affecting quantum processors, hence limited to only few operations. We propose an efficient approach for these simulations based on the implementation of quantum units with $d > 2$ levels (*qudits*). We demonstrate how the use of qudits results in a reduction of up to two orders of magnitudes in the number of operations (gates) required in the realization of state-of-the-art QS-OQS algorithms. In order to thoroughly explore the advantages and constrictions associated to qudit-based quantum simulations, we explore two conceptually distinct families of QS-OQS algorithms [1,2]. We discuss the gate complexity scaling that different platforms (qubit-based vs qudit-based, Fig. 1) offer when implementing these algorithms, which were initially designed for qubits.

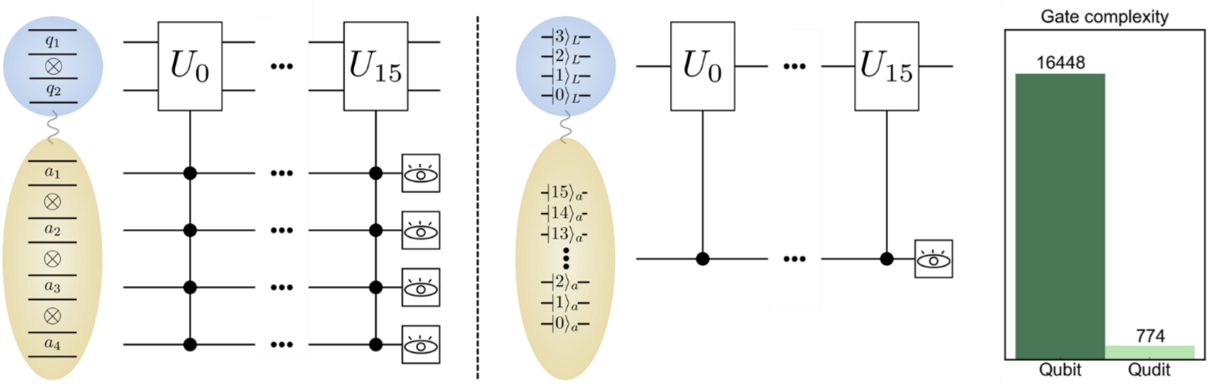

Fig.1 Schematization of the quantum simulation of the dynamics of a spin-3/2 particle coupled to a Markovian bath using one of the considered methods. Left: circuit for a hardware consisting of 2 qubits as the system and 4 qubits used to simulate the environment. Middle: circuit for a hardware consisting of a 4-level qudit as the system and a 16-level qudit used to simulate the environment. Right: gate complexity comparison between the two different platforms.

Additionally, we present realistic simulations of an experimental platform based on molecular spin qudits coupled to superconducting resonators (Fig. 2), where the main hardware error sources are included.

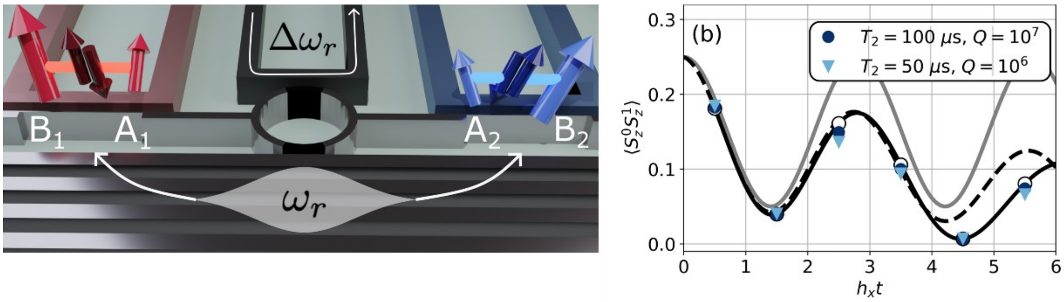

Fig. 2 Left: schematic design of the physical hardware proposed to simulate the dynamics of two spins A_1 and A_2 coupled to artificial environments B_1 and B_2, enabling entanglement between A_1 and A_2 through a resonator. Right: simulation results for a transverse-field Ising model ($J = 2h_x$, $h_x = 1$) in which both qubits are subjected to a depolarizing channel.

We show that, in all cases considered, the use of qudits leads to a remarkable reduction in circuit complexity and that molecular nanomagnets are ideal qudit hosts.

References

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