Emulating many-body localization with a superconducting quantum processor

With the support by the National Natural Science Foundation of China, an inter-institutional research group co-directed by Prof. Wang HaoHua (王浩华) at Zhejiang University, Prof. Zhu XiaoBo (朱晓波) at the University of Science and Technology of China, and Prof. Fan Heng (范桁) and Prof. Zheng DongNing (郑东宁) at the Institute of Physics, Chinese Academy of Sciences recently reported a quantum simulation experiment based on a 10-qubit superconducting quantum processor, where they successfully emulated the many-body localization (MBL) effect, an active topic in condensed matter physics, and observed the MBL hallmark, i. e., the long-time logarithmic growth of the system's entanglement entropy. The result was published in *Physical Review Letters* (2018, 120: 050507).

MBL exists in disordered systems featuring interacting particles, and it violates the law of statistical mechanics which states that closed quantum many-body systems initialized in nonequilibrium will thermalize under their own dynamics. On quantum simulation platforms such as optical lattice and nuclear spins, researchers have synthesized the MBL phase by controlling the disordered potential. However, the entanglement property of MBL, though widely explored theoretically, has not been experimentally investigated due to the experimental challenge in efficient multiqubit quantum state tomography.

The quantum processor used in this experiment integrates 10 transmon qubits featuring resonator-mediated qubit-to-qubit interactions, which can be mapped to an interacting many-body model. By tuning up the disordered potential, a crossover in phases from thermal to MBL was identified. With strong disorder, the system entered into the MBL phase in which any initial information could be retained. More importantly, with the fast and accurate detection technique for superconducting qubits, the hallmark of MBL, i. e., the long-time logarithmic growth of entanglement entropy, has been directly observed for the first time.

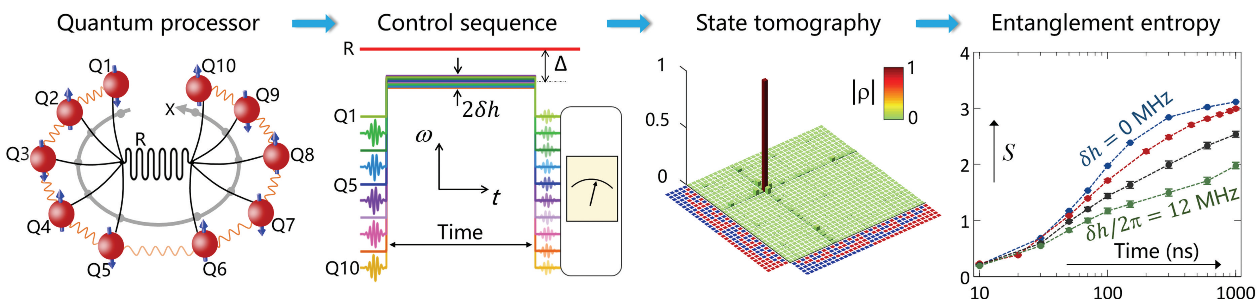

Figure Experimental process of emulating MBL using the quantum processor. With strong disorder as imposed by the control sequence, the system entered into the MBL phase, whose entanglement entropy increased logarithmically over time as probed by quantum state tomography.

This experimental accomplishment builds upon a series of recent technical advancements achieved by the same inter-institutional research group. Last year, using similar devices the research group reported the generation of the 10-qubit Greenberger-Horne-Zeilinger (GHZ) state, the largest GHZ entanglement created so far in solid-state systems, and the high-fidelity multiqubit controlled phase gates with up to 4 qubits. All of these experimental results lay solid foundations for precisely simulating the intriguing physics of quantum many-body systems on the platform of large-scale multiqubit superconducting quantum processors.