Spectral signatures of many-body localization of interacting photons

P. Roushan[1], C. Neill[2], J. Tangpanitanon[3], V.M. Bastidas[3], A. Megrant[1], R. Barends[1], Y. Chen[1], Z. Chen[2], B. Chiaro[2],A. Dunsworth[2], A. Fowler[1], B. Foxen[2], E. Jeffrey[1], J. Kelly[1], E. Lucero[1], J. Mutus[1], M. Neeley[1], C. Quintana[2], D. Sank[1], A. Vainsencher[2], J. Wenner[2], T. White[1], H. Neven[1], D. G. Angelakis[3,4], J. Martinis[1,2]

[1]Google Inc., Santa Barbara, California, USA
[2]Department of Physics, University of California, Santa Barbara, California, USA
[3]Centre for Quantum Technologies, National University of Singapore, Singapore
[4]School of Electrical and Computer Engineering, Technical University of Crete, Chania, Crete, Greece

Statistical mechanics is founded on the assumption that a system can reach thermal equilibrium, regardless of the starting state. Interactions between particles facilitate thermalization, but, can interacting systems always equilibrate regardless of parameter values ? The energy spectrum of a system can answer this question and reveal the nature of the underlying phases. However, most experimental techniques only indirectly probe the many-body energy spectrum. Using a chain of nine superconducting qubits, we implement a novel technique for directly resolving the energy levels of interacting photons. We benchmark this method by capturing the intricate energy spectrum predicted for 2D electrons in a magnetic field, the Hofstadter butterfly. Increasing disorder leads to the formation of a mobility edge, where the spatial extent of energy eigenstates shrink at the edge of the energy band. At strong disorder, the energy levels cease to repel one another and their statistics approaches a Poisson distribution - the hallmark of transition from metallic to the many-body localized phase. Our work introduces a new many-body spectroscopy technique to study quantum phases of matter.

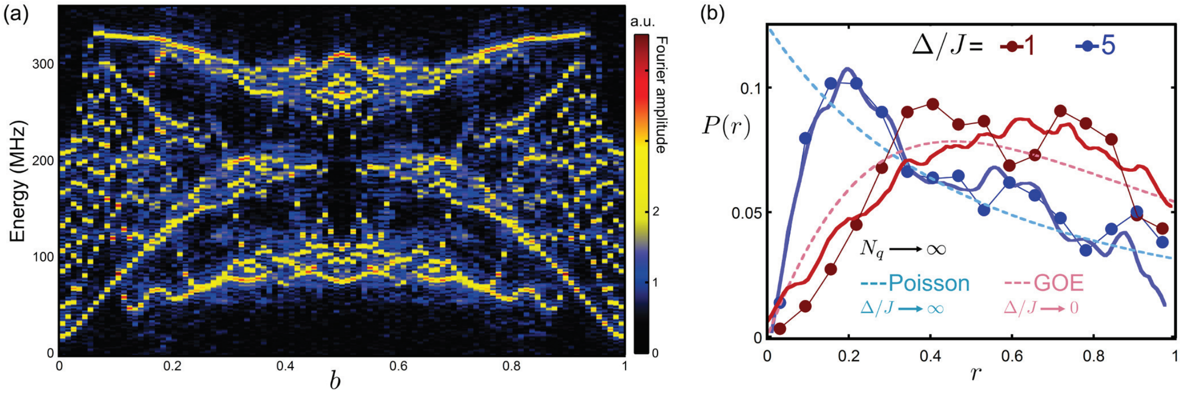

Figure 1. (a) Experimental realization of Hofstadter butterfly with our 9 qubit chain. (b) We use the distribution of the energy levels to study ergodic dynamics and its breakdown. When there are two photons in the system, for small disorder, the measured histogram of levels shows GOE distributions, which is predicted when the energy eigenstate repel each other. For large disorder, the histogram tends toward a Poisson distribution, which is the signatory of transition to the many-body localized phase.