Probing chaos and ergodicity in programmable quantum matter
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A long-standing challenge in the field of statistical mechanics has been defining notions of chaos and ergodicity in quantum regimes. For instance, the widely-accepted definition of quantum chaos hinges on the random matrix theory (RMT) behavior of eigenstates. However, the RMT description primarily captures the coarse-grained behavior of quantum states, e.g. their volume-law entanglement entropy. In this talk, I will discuss how richer universal structures emerge when studying the fine-grained correlations---or higher statistical moments---of quantum state ensembles beyond RMT. Importantly, such fine-grained correlations are now measurable in programmable quantum matter---large-scale systems whose basic constituents can be individually controlled at the quantum level---and are quite relevant in quantum applications, such as characterizing how much randomness a quantum device can generate. First, I will show that spatial locality and energy conservation is imprinted in the structure of eigenstate ensembles of physical (i.e., spatially local and finite local Hilbert space) Hamiltonian systems, and how these features can be incorporated into RMT descriptions [1,2]. I will also show that physical Hamiltonians can exhibit `maximally chaotic' behavior in which eigenstates are maximally entropic given the constraints of locality and energy conservation[1]. Separately, I will show that midspectrum (or high energy) states evolving under quantum chaotic Hamiltonian dynamics, which are typically expected to evolve into features states at late times, can still exhibit rich classes of universal behaviors at late times when looking at their higher statistical moments [3].

References:
[1] JRN, Jonay, and Khemani, PRX 14, 031014 (2024).
[2] Langlett and JRN, arxiv/2403.10600.
[3] Ghosh, Langlett, Hunter-Jones, and JRN, arxiv/2409.02187.