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## A Universal Analog Quantum Simulator Using Atomic Spins[1]

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Progress in quantum information science has created a need for experimental platforms that lend themselves to critical evaluation of various paradigms for quantum control and diagnostics. We have developed one such platform using the electron-nuclear spins of individual Cs atoms, forming a 16-dimensional state space that is fully controllable with phase modulated radio-frequency and microwave magnetic fields. Recent work includes the implementation of arbitrary unitary control with state-of-the-art fidelity, and a comparison of optimal strategies for quantum state tomography. The degree of control achievable with this system also allows it to be used as a universal, high-fidelity Analog Quantum Simulator. Broadly defined, an AQS is a controllable quantum system whose time evolution can emulate a Hamiltonian of interest. If used to simulate complex dynamics without error correction such a device becomes vulnerable to exponential loss of precision due to small imperfections. In the classical world this phenomenon manifests itself as deterministic chaos, wherein small perturbations are exponentially amplified over time. Given that imperfections are unavoidable in the real world, this raises the fundamental question whether one can trust the output of an AQS. As a step towards addressing these issues, we are using our AQS to simulate a popular paradigm for quantum chaos, the Quantum Kicked Top, consisting of a periodically driven spin whose classical phase space can be regular, chaotic, or mixed. For our work we pick a spin $J=15/2$, map the $2J+1=16$ spin states onto our AQS, and use optimal control to drive up to a few hundred periods of the QKT dynamics. Our experimental results shed light on several questions of general interest: Is there an optimal map from system to simulator? How accurate must the control be to allow meaningful simulation? And how long can we simulate before the physics of interest (phase space structure, critical points, scrambling, etc.) is compromised by control errors?

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