Quantum simulation with driven-dissipative superconducting circuits
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Superconducting Circuits for Quantum Simulation
- 53 qubit 2D-array
- lattice on hyperbolic surface
- Extended Bose-Hubbard lattice

Google Sycamore (2019)
Košler et al., Nature (2019)
X. Zhang, E. Kim et al., arXiv:2206.12803

- Digital quantum simulation with NISQ devices
- Analog quantum simulation for lattice physics, waveguide QED, etc.

Synthetic quantum material in Circuits
- Advantages of SC circuits for quantum simulation:
  - Long lifetime in superconducting cavities (milliseconds to seconds)
  - Strong coherent interaction realized in circuit QED
  - Flexibility in engineered dispersion, coupling, connectivity etc.

Great platform for studying many-body physics of synthetic quantum materials made of microwave photons

Drive-dissipative stabilization Mott-Insulator state

On-site interaction of transmon qubits:
- Transmon qubit as an anharmonic oscillator provide effective on-site interaction $U$ for microwave photons


Different ways to engineer coupling:
- Direct Nearest-neighbor coupling of transmon qubits
- Coupling via shared waveguide
- Tunable coupling via virtual photon exchange path
- Dynamically tunable parametric coupling


Bath engineering
- Precise, tunable control of coupling to dissipative environments.
- Driven-dissipative stabilized quantum state/phase
- Intrinsic dissipation makes it natural to study open quantum systems

Müller, Nature (2012)

Generating ‘Rainbow’ State
- Motivation: Dissipative stabilized long-range entanglement with only NN tunneling and one local bath
- Theory prediction: Pocklington, PRB 105, L140301 (2022)

P. O. Guimard et al., npq quantum information (2019)

- Mechanism: 2 qubit couple to the same lossy cavity via parametric red/blue sideband coupling -> effectively correlate correlated loss and gain channel

Experimental device fabrication - on going

Bath-coupled Bose-Hubbard lattice
- Driven dissipative stabilized many-body ground state

- Our focus: Towards strong correlated phase, e.g. strongly interacting super-fluid state

- Engineer effective chemical potential for light with broadband bath

- Our plan: Parametrically enabled coupling + variable linewidth + frequency modulation for dynamically tunable spectra

Dynamics/correlation in lattices coupled to local baths
- Theory proposal: S. Dutta, PRR (2021)
- Experimental setting:
  - Tunable coupled qubit array
  - Locally coupled gain and loss bath
  - Fast readout cavity

- The readout resonator also serve as a knob to explore the interplay between
  - Coherent interaction
  - Driven-dissipation
  - Measurement back action/feedback

Other directions
- Using superconducting circuits to probe (real) quantum materials
- Chiral quantum optics
- Robust quantum resources for QIP (quantum information processing)