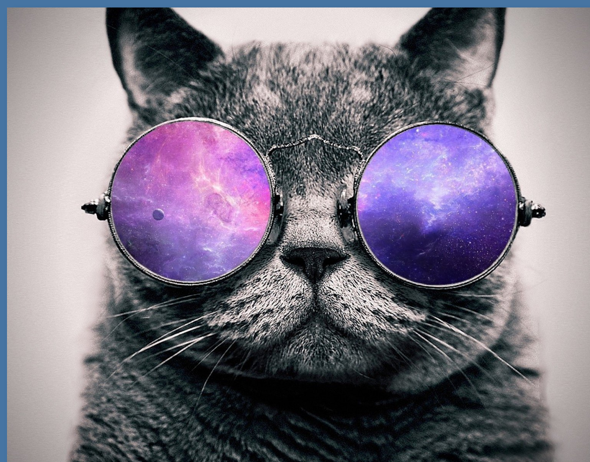
Superconducting qubits $|101\rangle$



Johannes Pollanen

MICHIGAN STATE UNIVERSITY

MSU-Q: Center for Quantum Computing Science and Engineering

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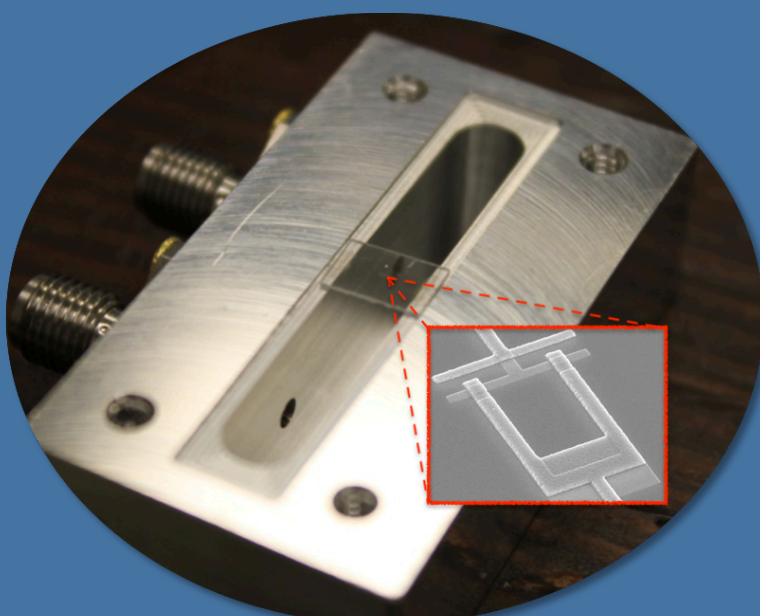
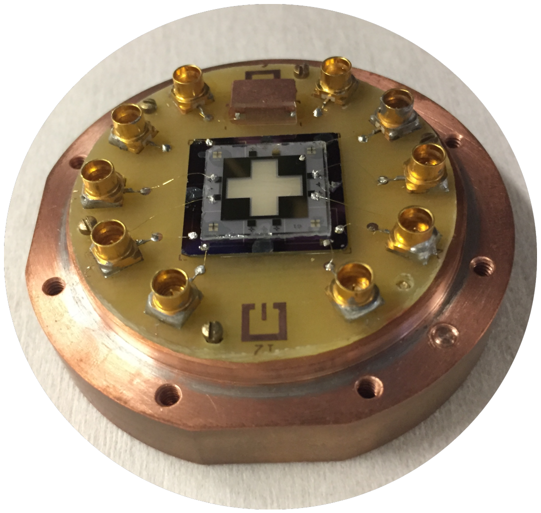
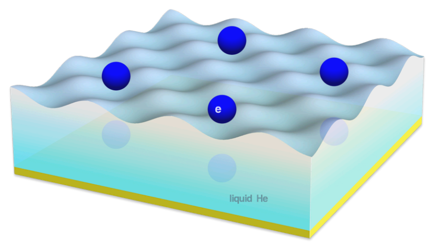
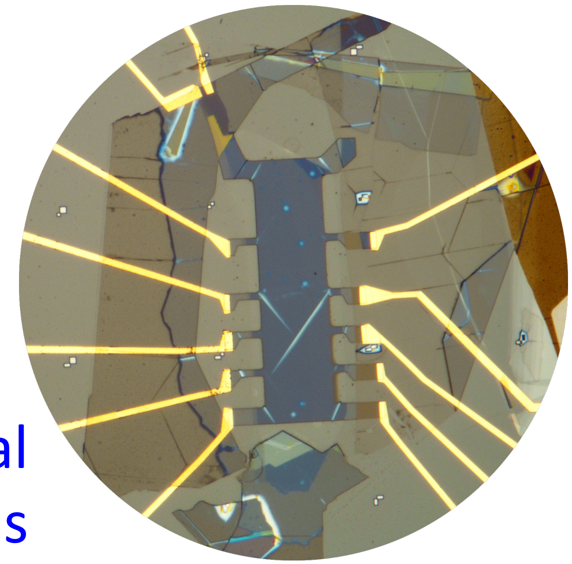


Laboratory for Hybrid Quantum System

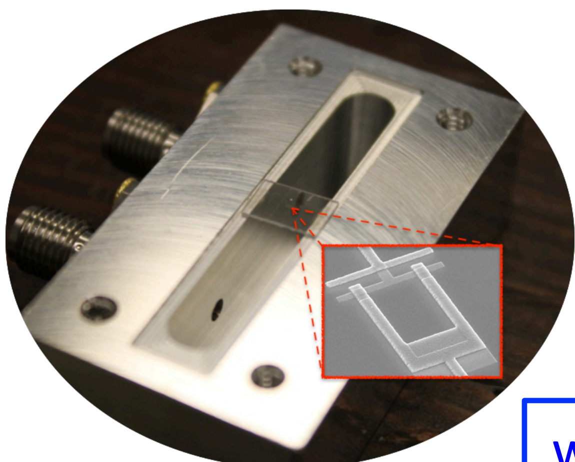


Hybrid systems with
electrons on helium





Quantum states in low-dimensional
electron systems



Superconducting
circuit based qubits

www.hybridquantumlab.com

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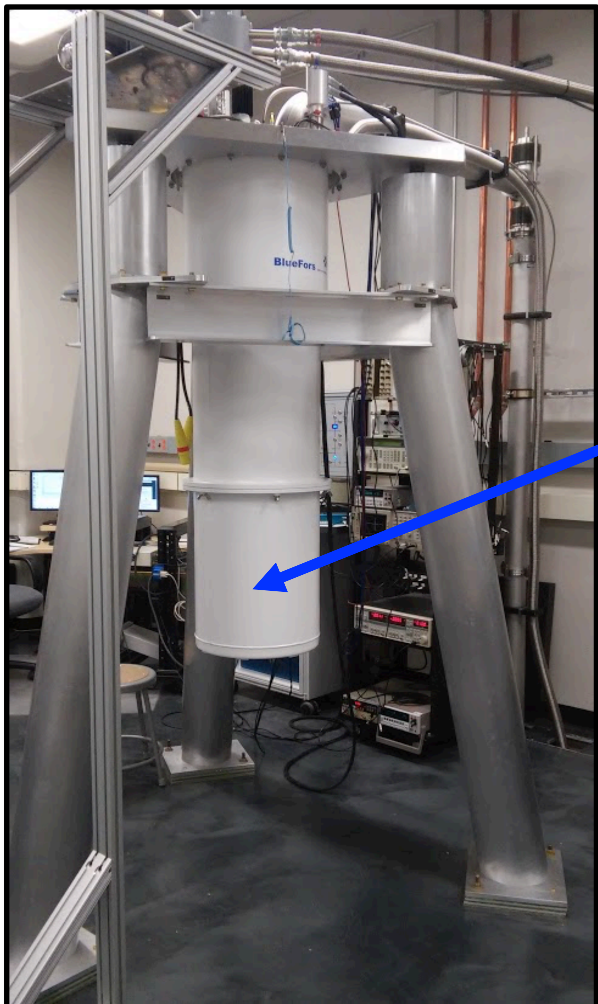
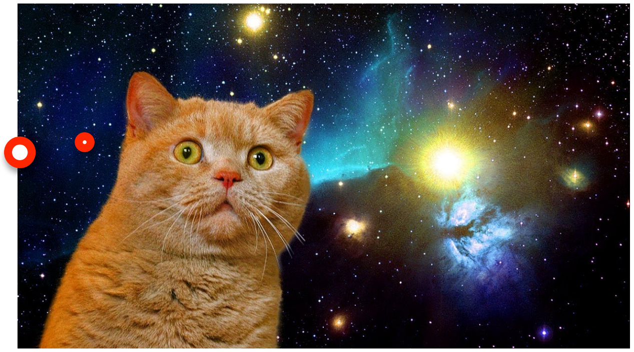
Conditions required for quantum

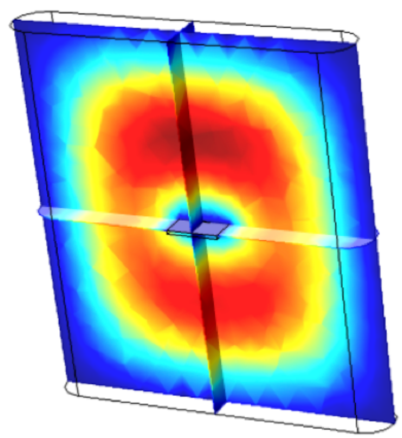


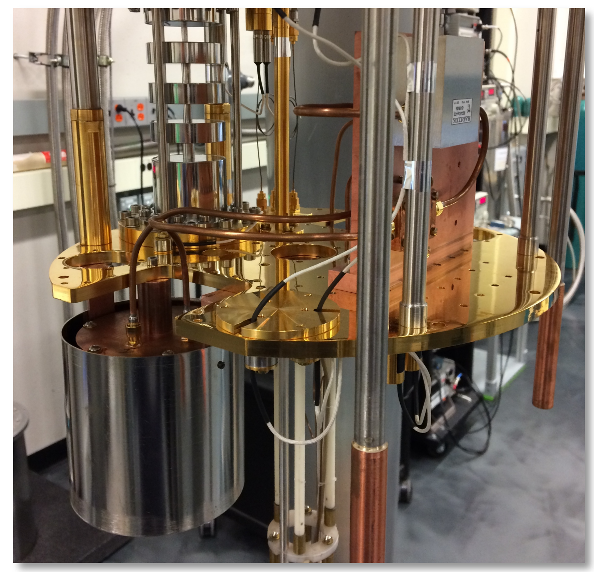
interstellar space: 2.7 K

outer space is tropical



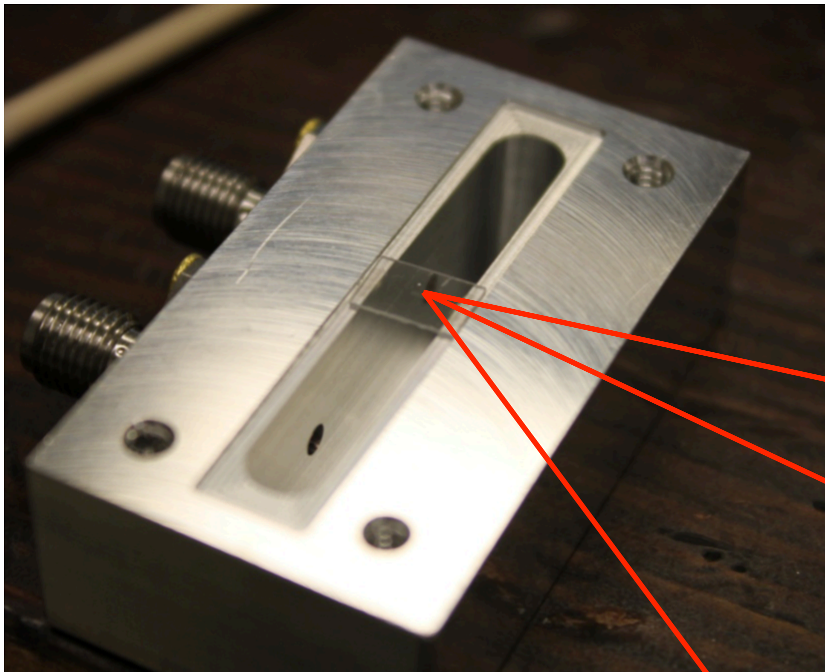
- low temperature
  (10 mK = -460 °F = -271 °C)

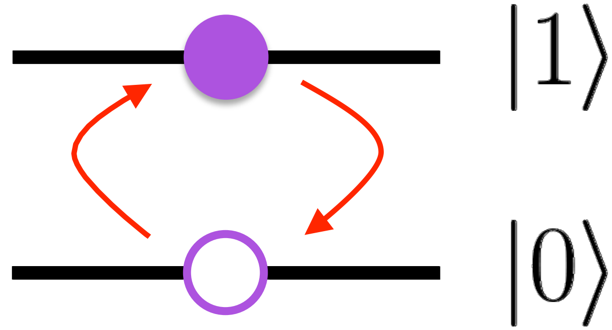


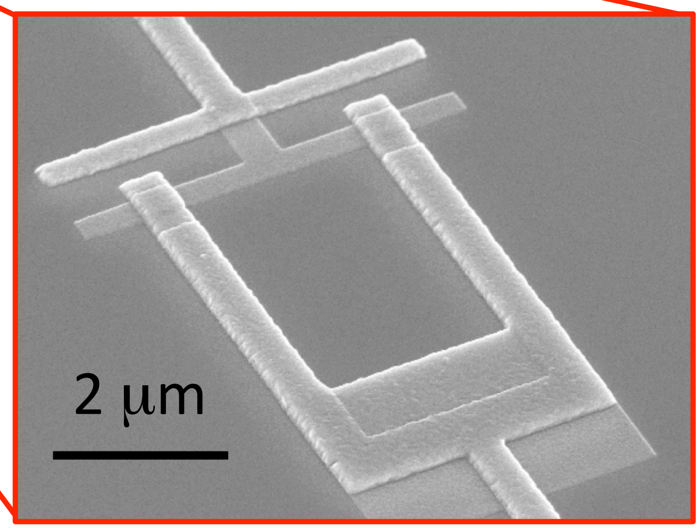


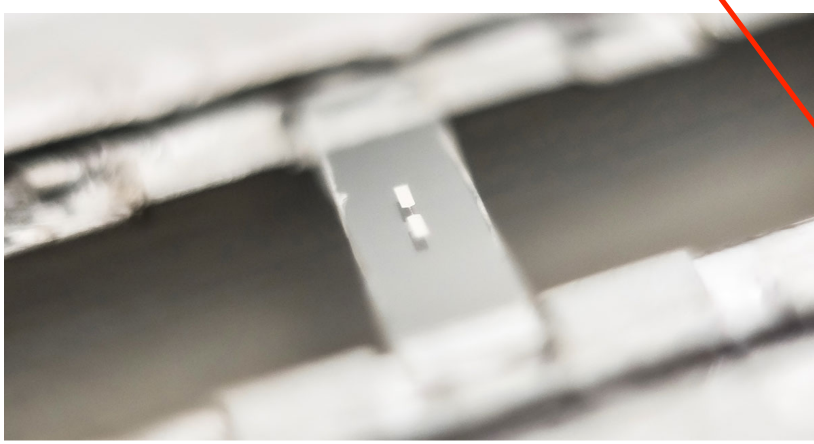
- sensitive electrical + microwave measurements (pV and fA)

Superconducting qubits (at the LHQS)

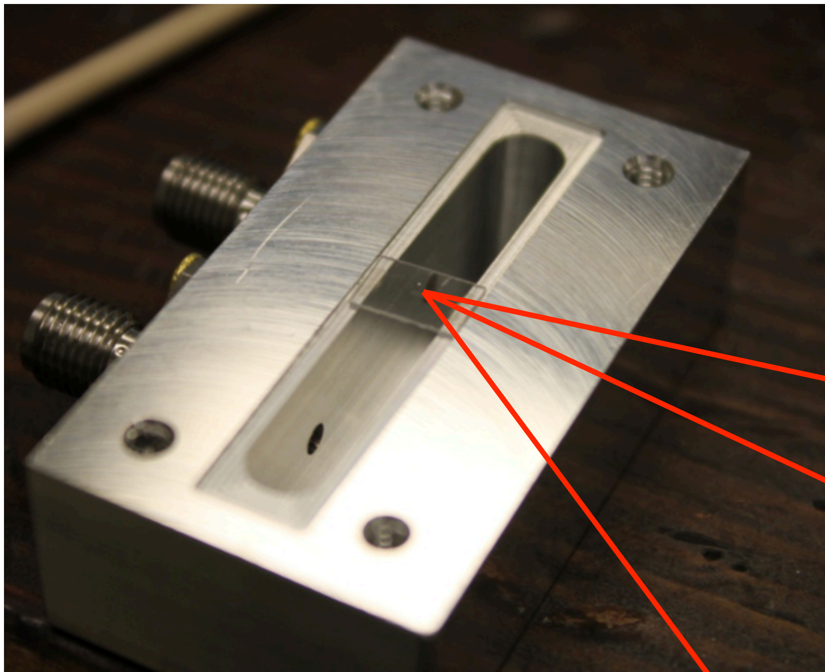


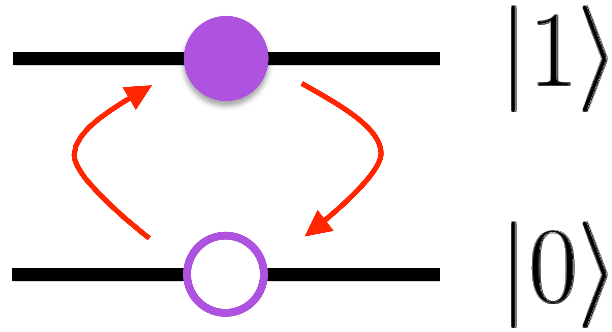


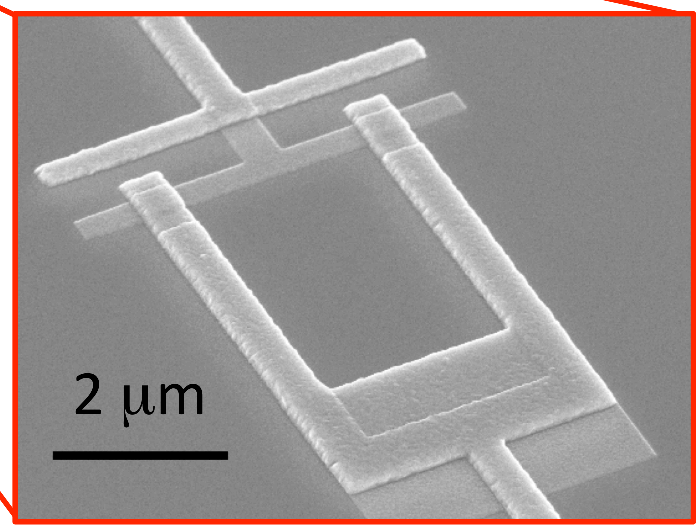


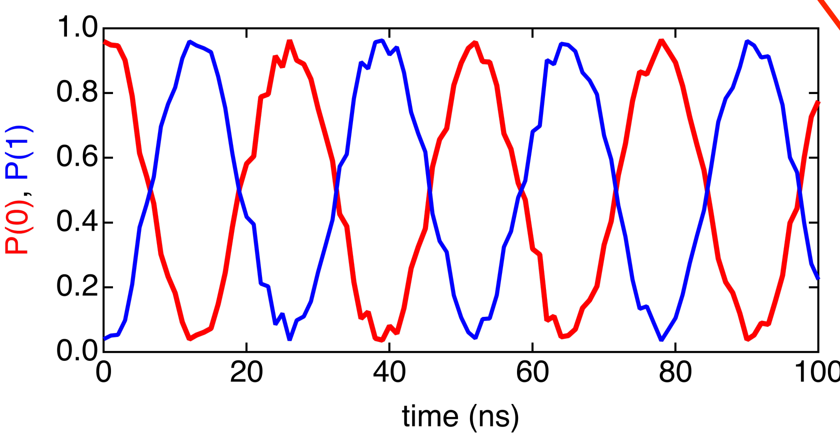


Superconducting qubits (at the LHQS)

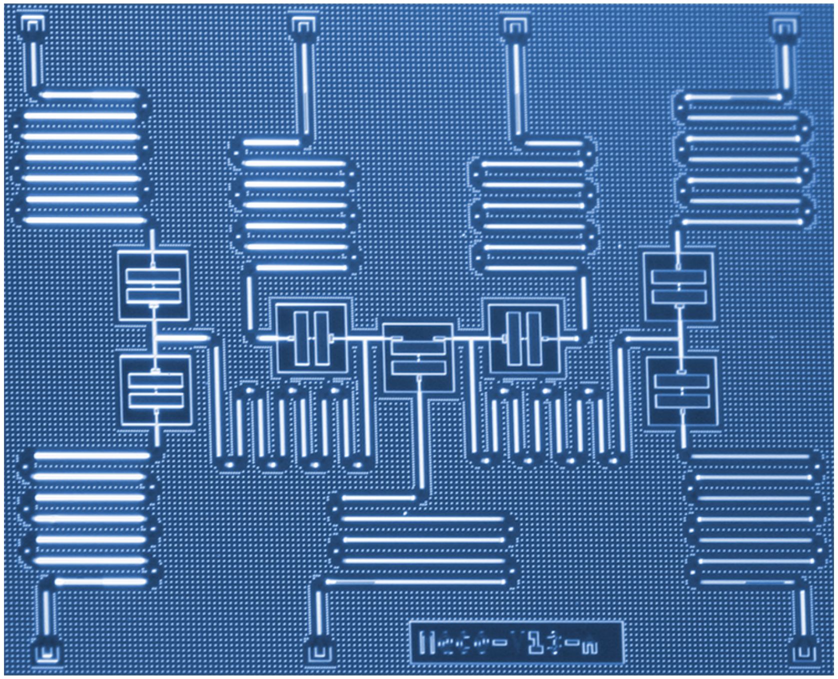


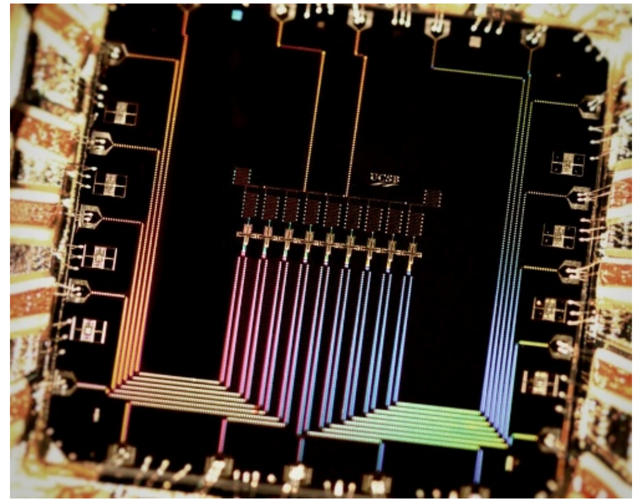


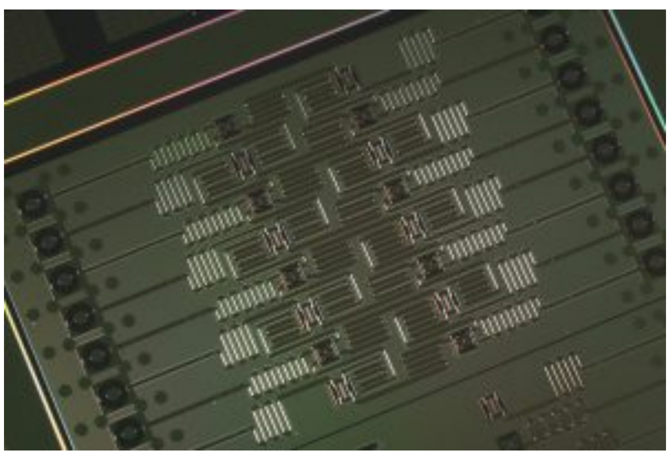


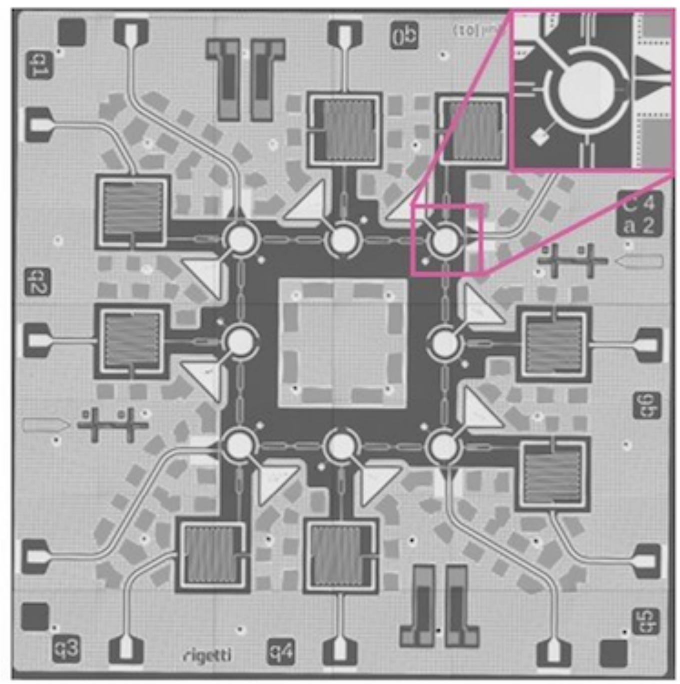


Planar superconducting qubits

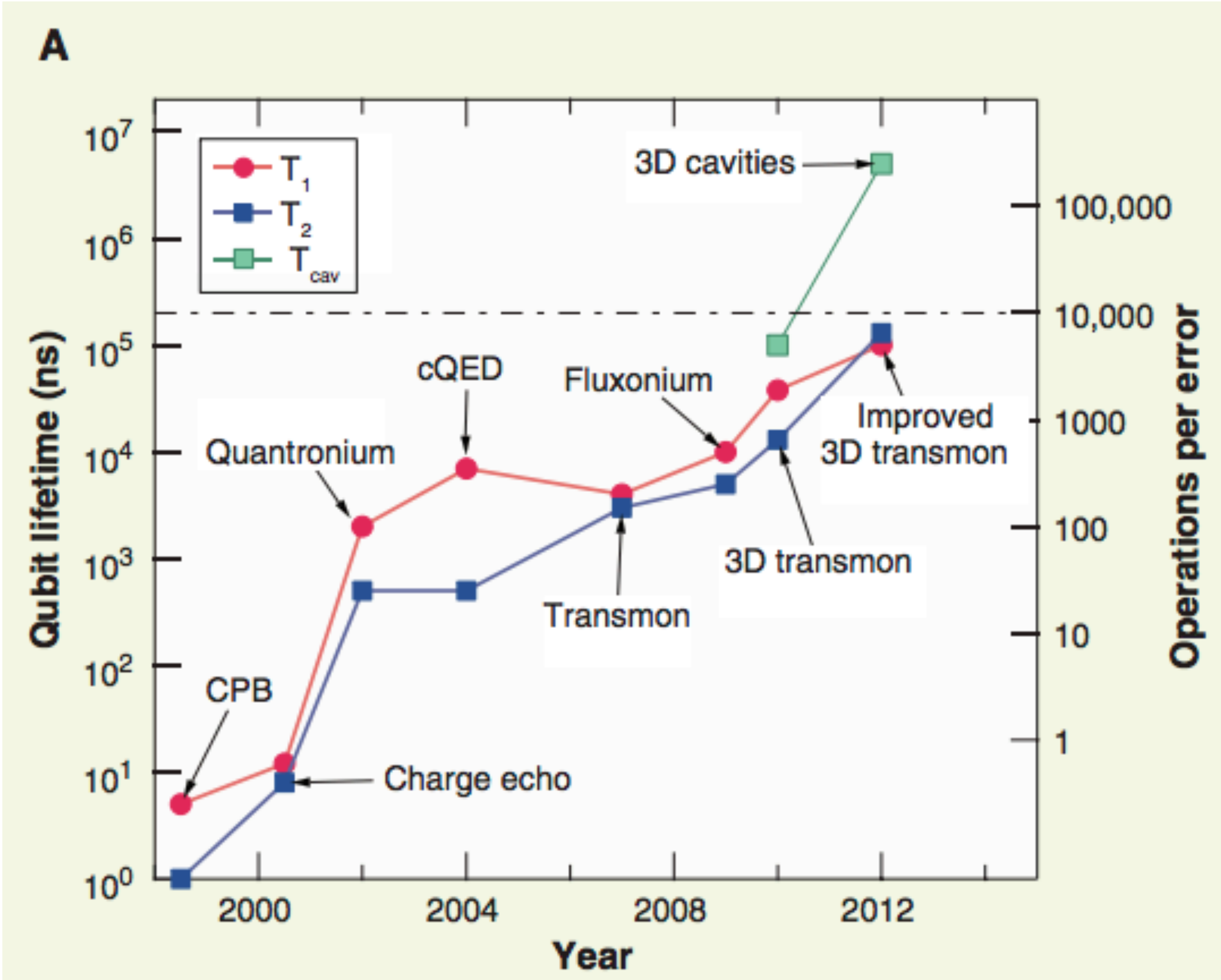








Superconducting qubits

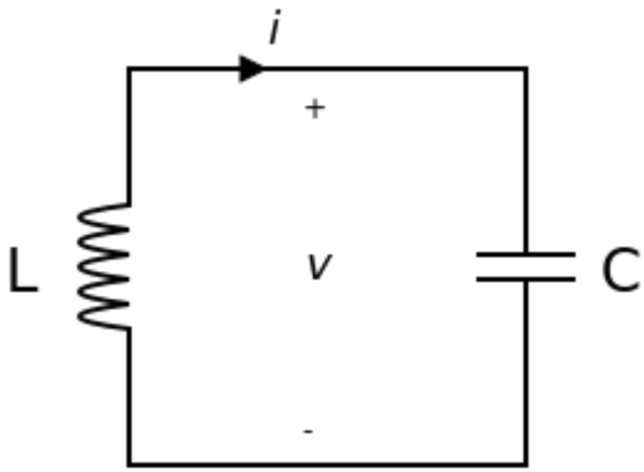


Devoret and Schoelkopf, **Science** 339, 1169 (2013)

Superconducting qubits

How do we make a quantum two level system from a circuit?

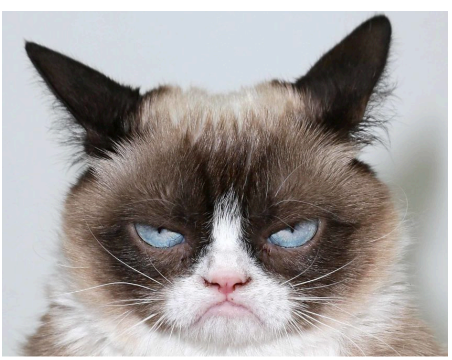
Quantum states are delicate: we want a **dissipationless** (superconducting) circuit



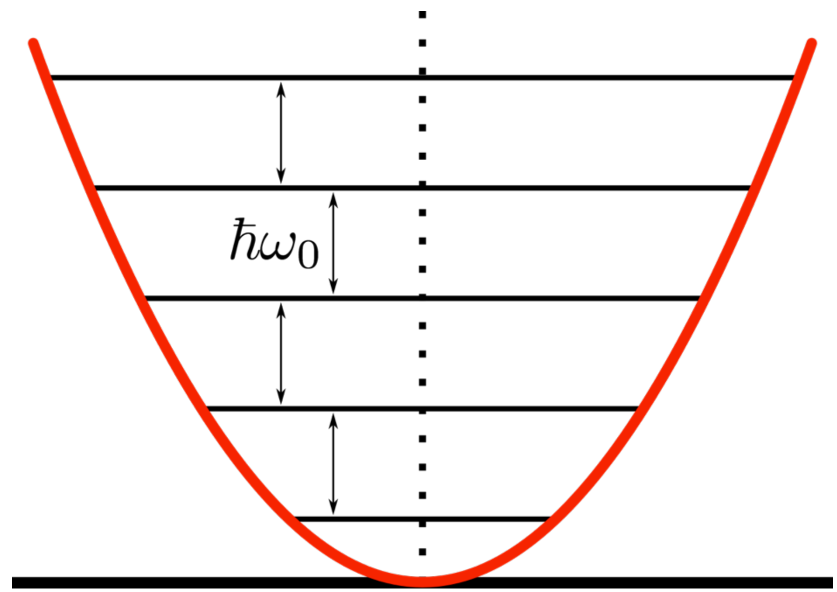
$$E = \frac{1}{2}LI^2 + \frac{1}{2}CV^2$$

$$H = \frac{\Phi^2}{2L} + \frac{Q^2}{2C} \qquad [\hat{\Phi}, \hat{Q}] = i\hbar$$

How about an LC oscillator?

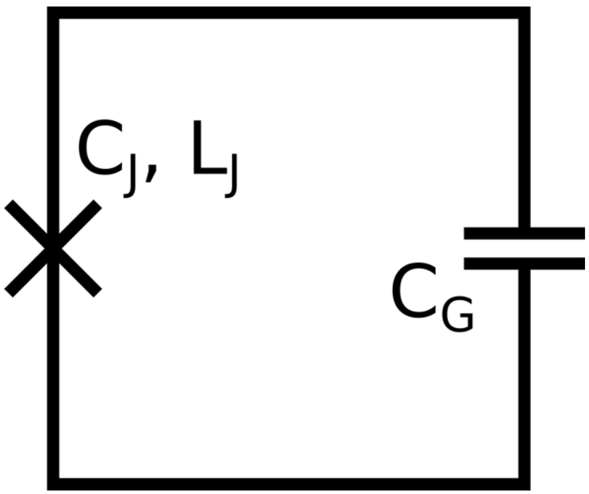


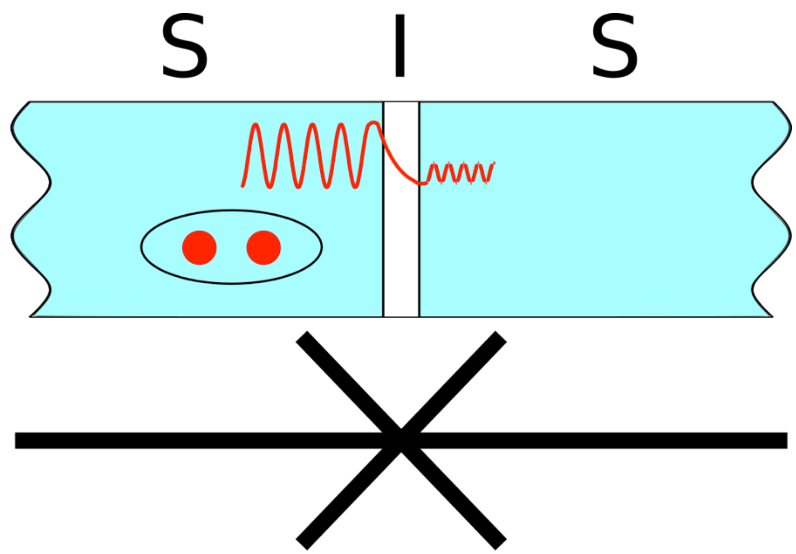
Nope



Superconducting qubits

Nonlinearity introduced by a **Josephson junction**



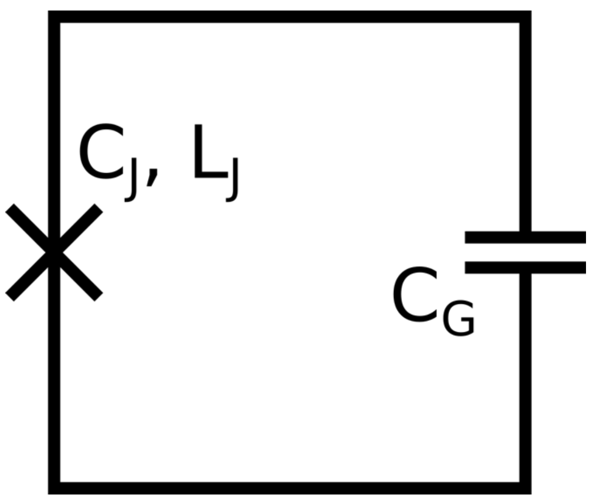


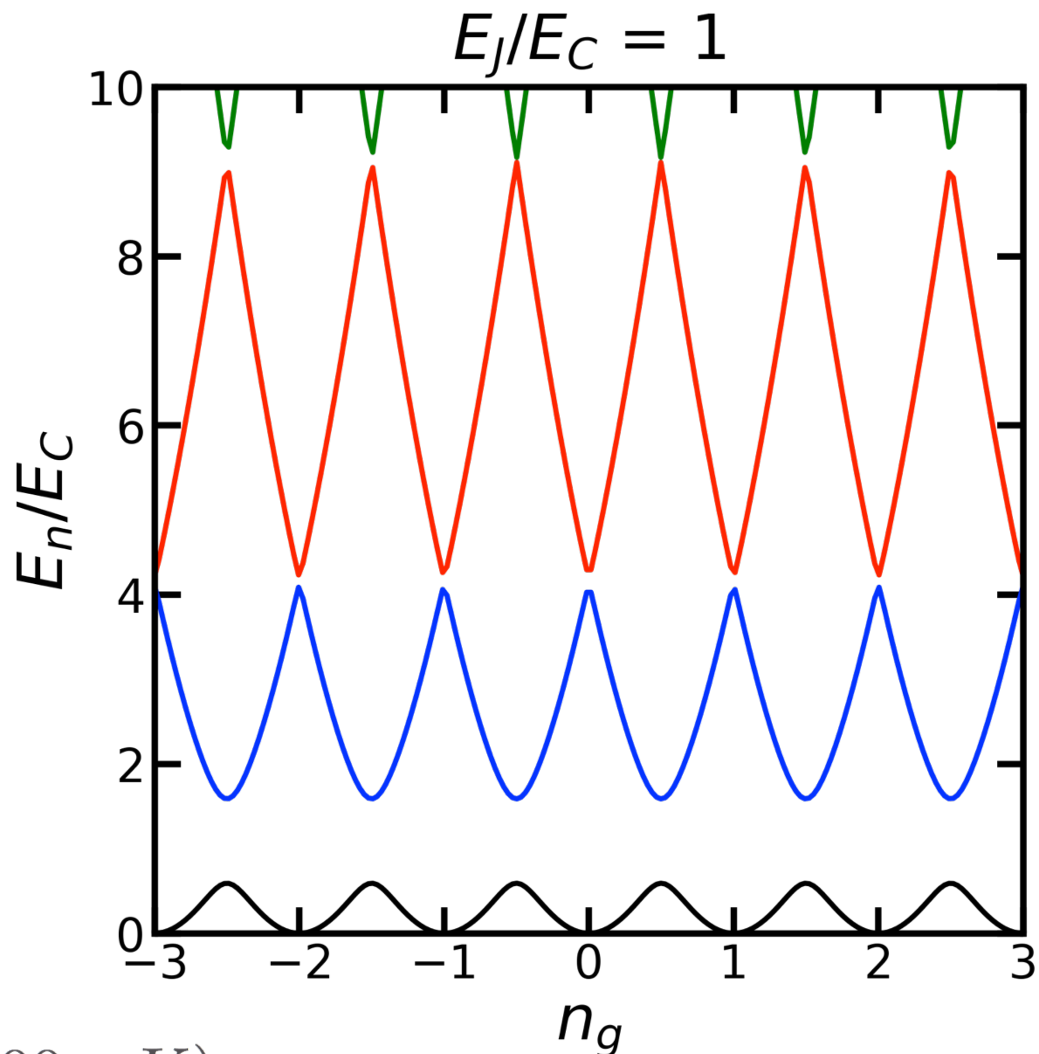
$$L \rightarrow L_J = L_{J0}/\sqrt{1-(I/I_0)^2}$$

$$\hat{H} \rightarrow 4E_C(\hat{N}-n_g)^2 - E_J cos(\hat{\phi})$$

$$E_C = e^2/2C_\Sigma, E_J = \hbar I_0/2e$$

Superconducting qubits



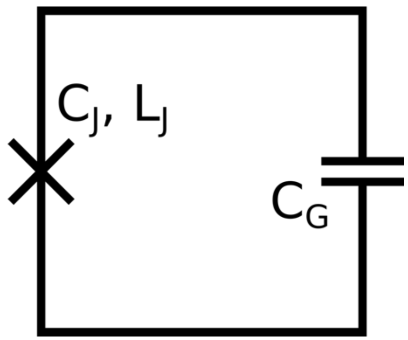


$\omega_{01} \sim 4 - 8$ GHz (250-500 mK)

Superconducting qubits

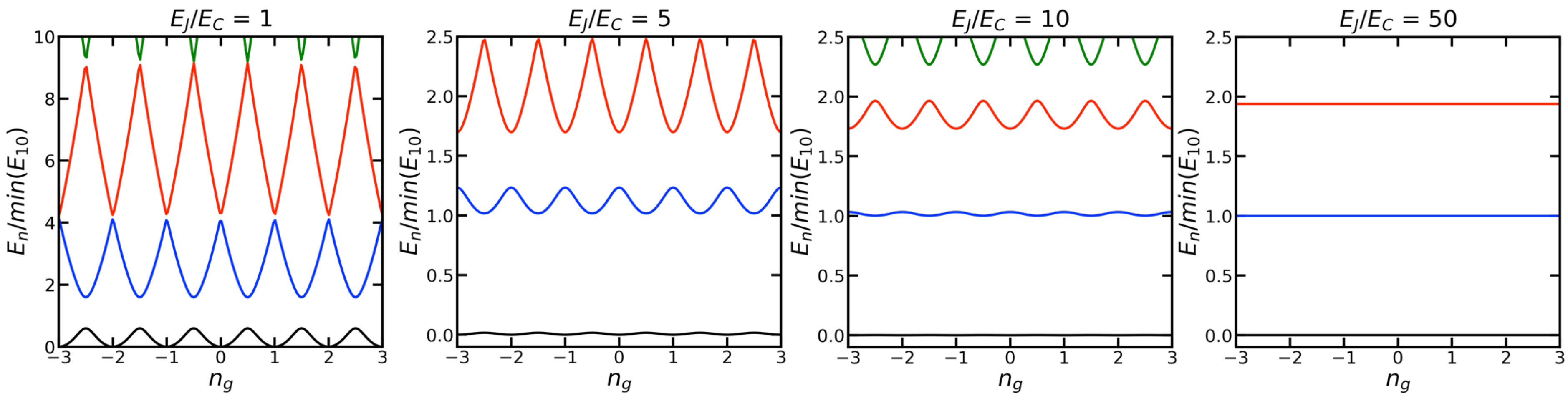
$$\hat{H} \rightarrow 4E_C(\hat{N} - n_g)^2 - E_J cos(\hat{\phi})$$

$$E_C = e^2/2C_\Sigma, E_J = \hbar I_0/2e$$

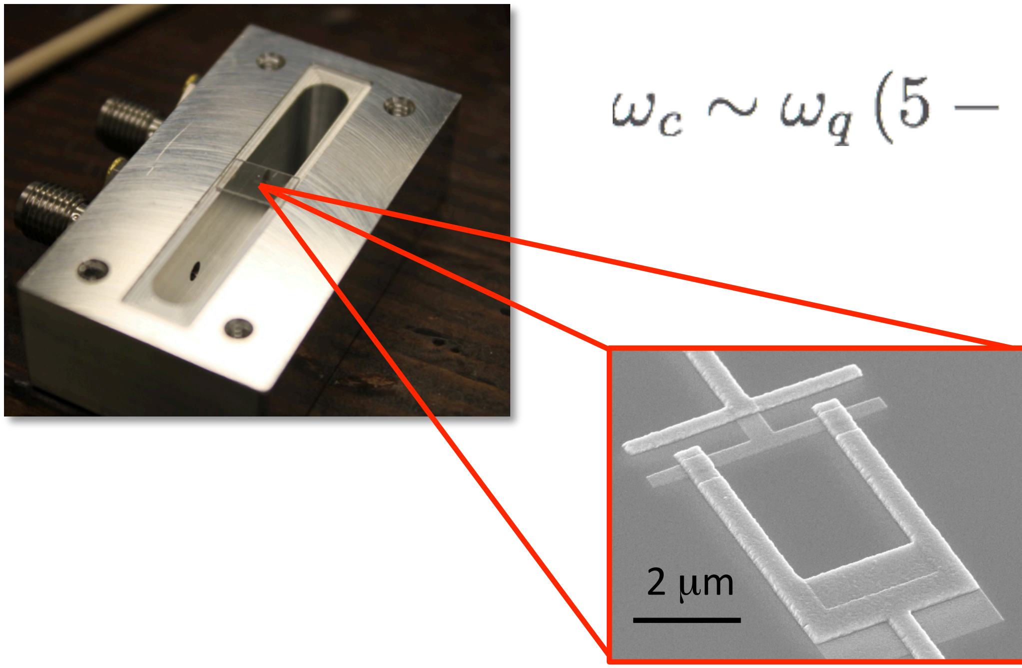


1999 ~ 1 ns

2019 ~ 100 μs



Circuit quantum electrodynamics (cQED)



$$\omega_c \sim \omega_q \; (5 - 10 \text{ GHz})$$

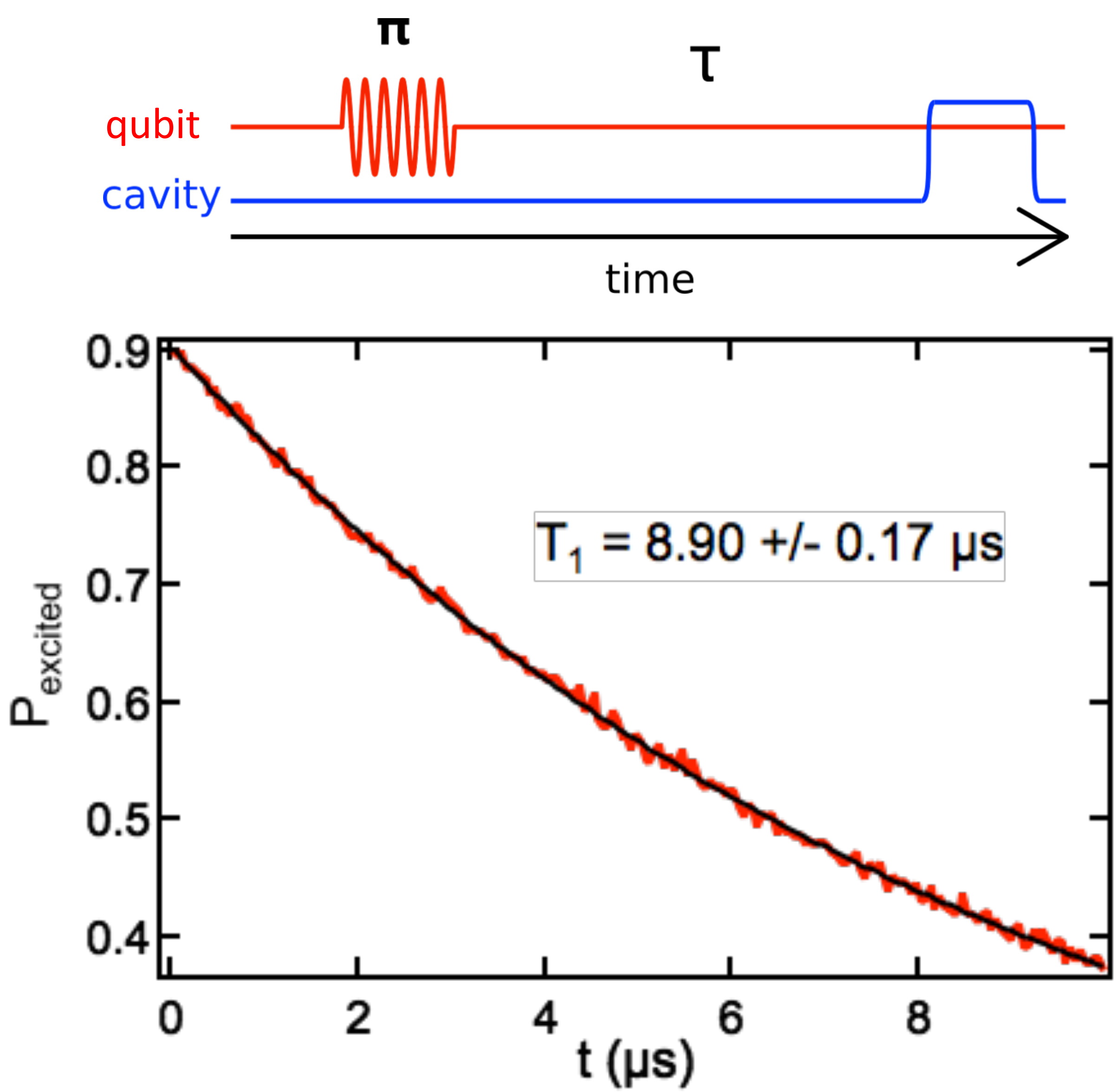
How do we measure/ control a transmon qubit exactly?

Borrow from quantum optics: place the qubit in a **microwave cavity**

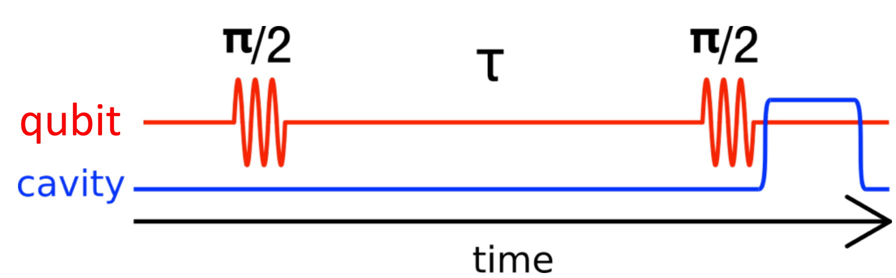
Governed by the Jaynes-Cumming Hamiltonian:

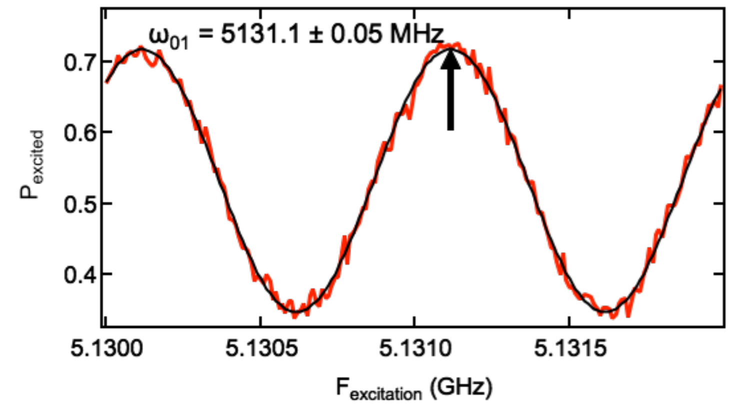
$$\mathbf{H_{JC}} = \frac{\hbar\omega_q}{2}\sigma_z + \hbar\omega_c(a^\dagger a + 1/2) + \hbar g(a^\dagger\sigma_- + a\sigma_+)$$

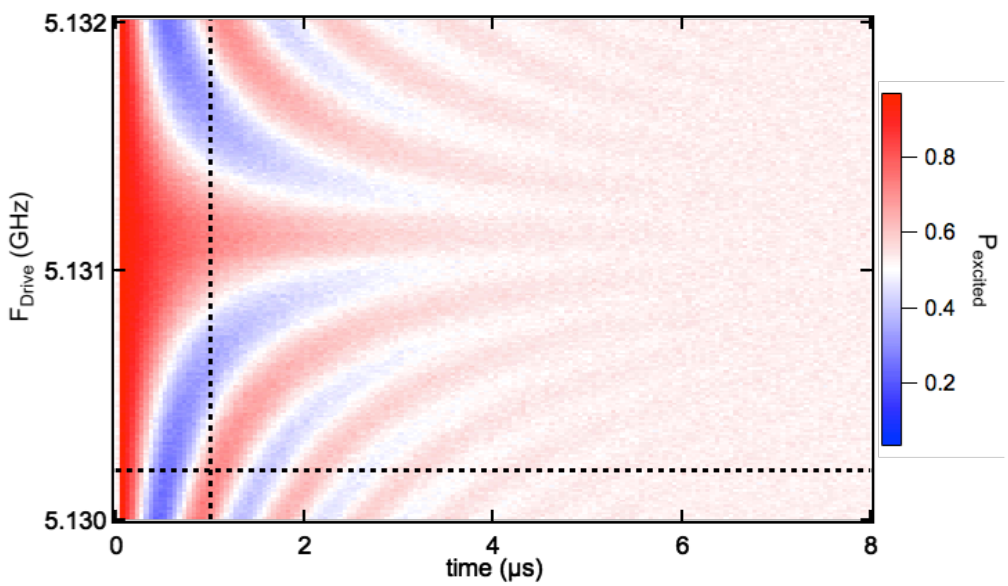
Measuring qubit decoherence (T_1)

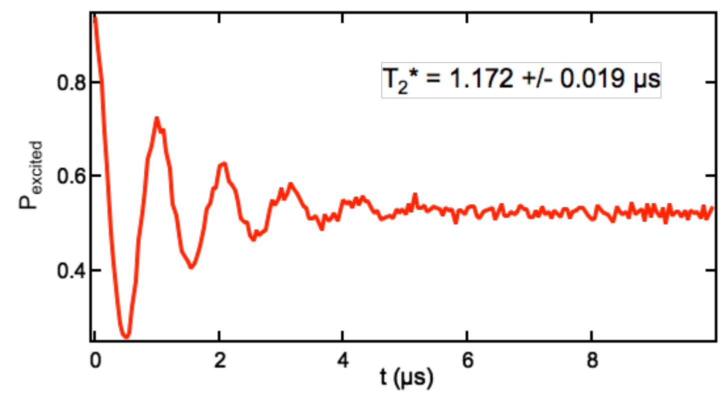


Measuring qubit decoherence (T_2)

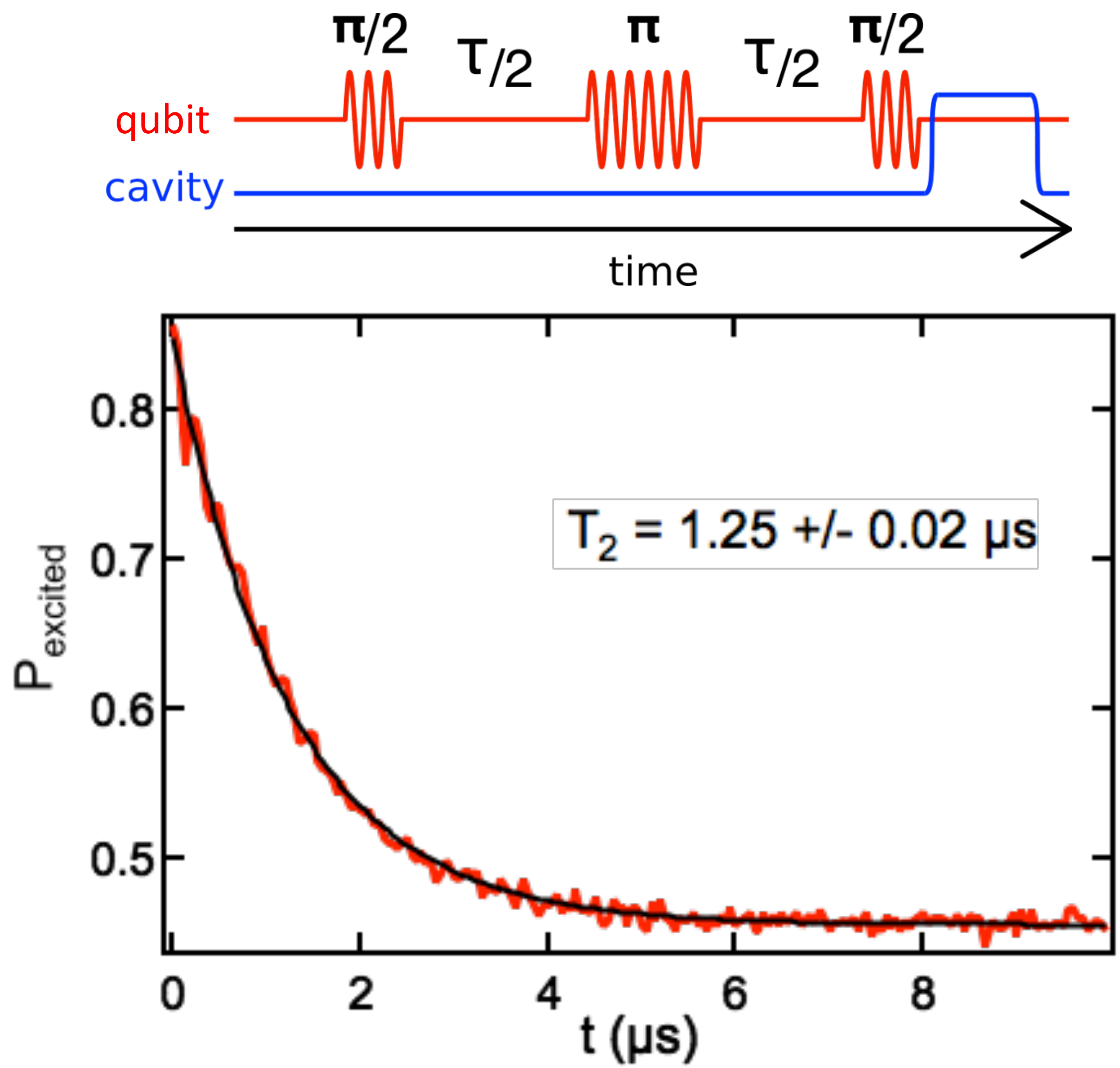




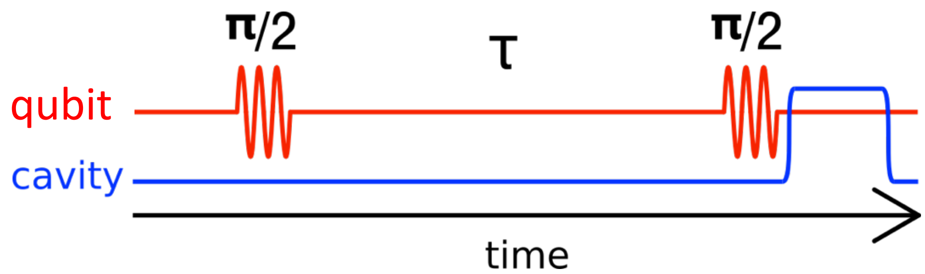


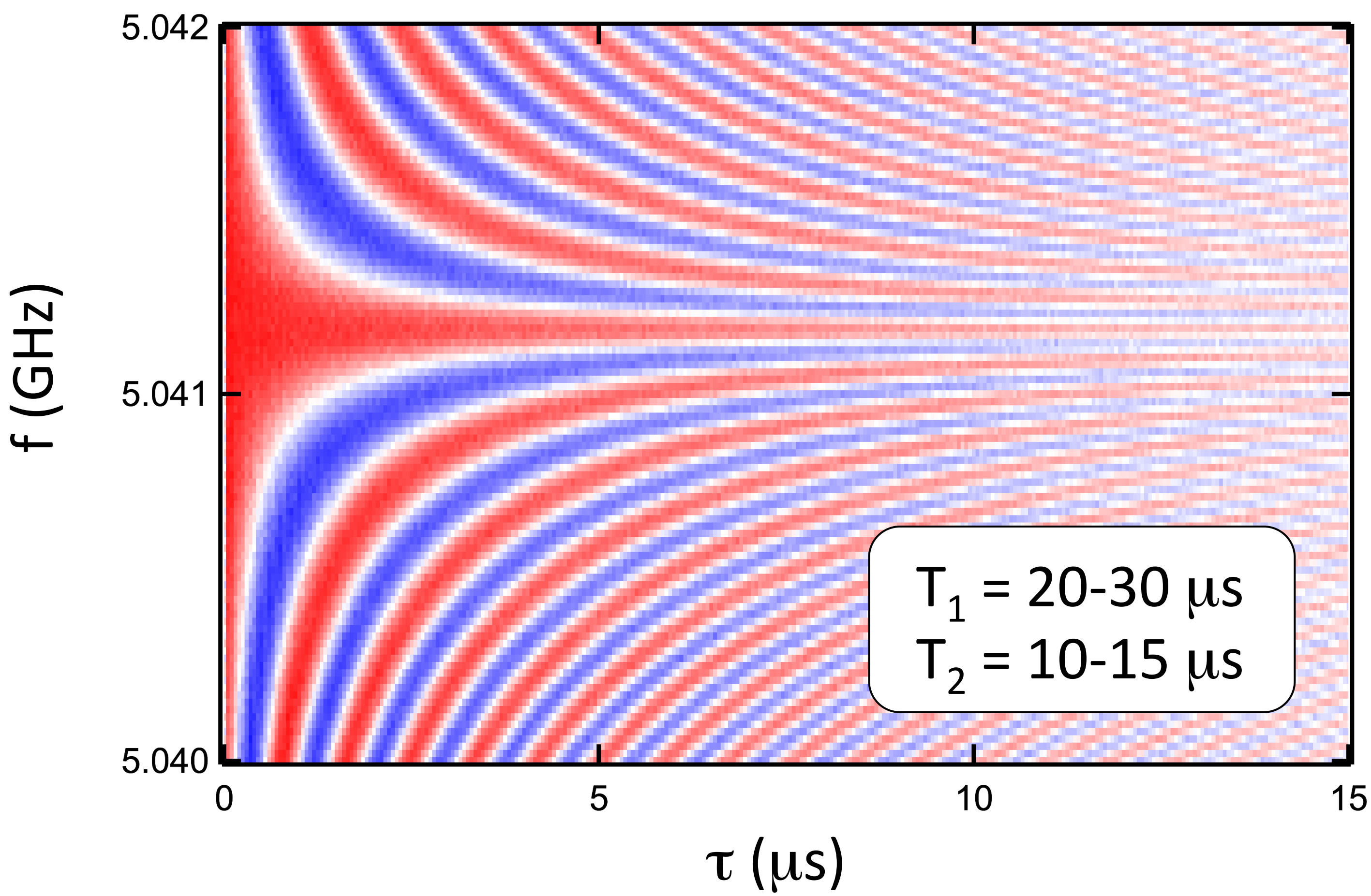


Measuring qubit decoherence ($T_{2,echo}$)



LHQS + WashU collaboration





Washington University in St. Louis