

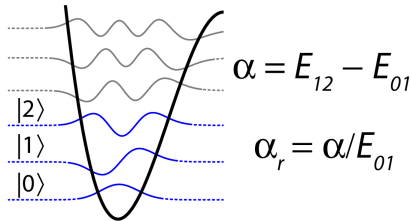
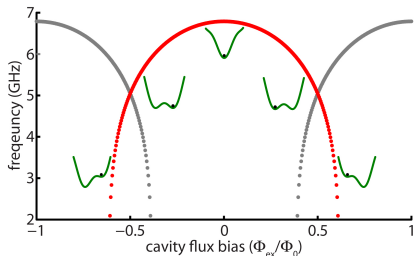
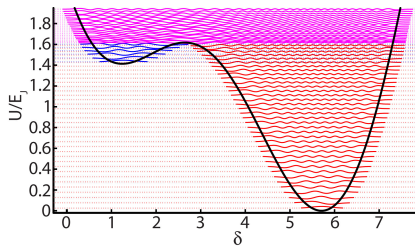
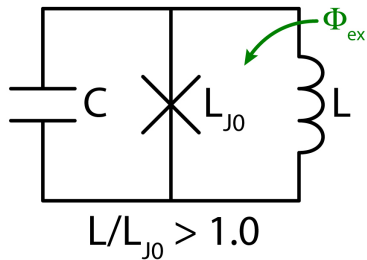
# Dispersive measurement of a phase qubit using a tunable cavity

Jed D. Whittaker, Michael S. Allman, Fabio da Silva, Florent Lecocq  
Katarina Cicak, Adam J. Sirois, John D. Teufel, José A. Aumentado,  
Raymond W. Simmonds

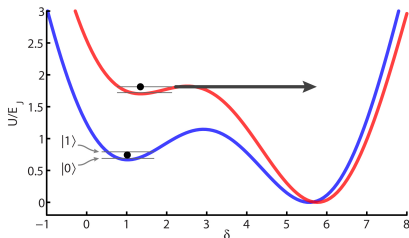
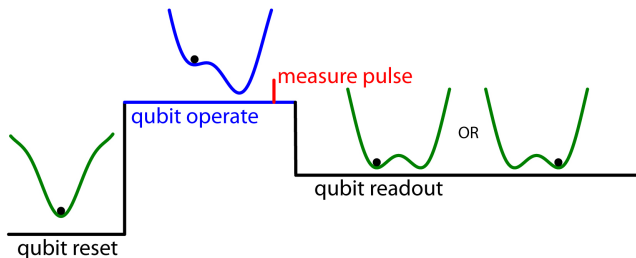
NIST/CU

March 21, 2013

# The phase qubit



# Phase qubit tunneling measurement

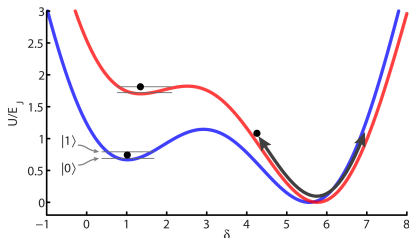
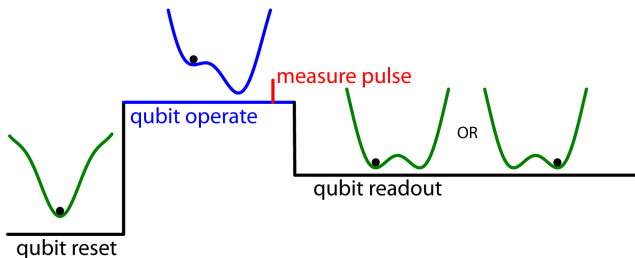


R. McDermott et al, **Simultaneous State Measurement of Coupled Josephson Phase Qubits** *Science* **307** 1299 2005

F. Altomare et al, **Measurement crosstalk between two phase qubits coupled by a coplanar waveguide** *Physical Review B*

**82** 094510 2010

# Phase qubit tunneling measurement

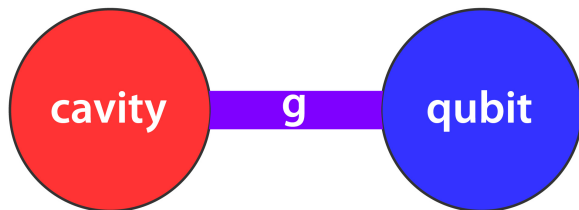


R. McDermott et al, **Simultaneous State Measurement of Coupled Josephson Phase Qubits** *Science* **307** 1299 2005

F. Altomare et al, **Measurement crosstalk between two phase qubits coupled by a coplanar waveguide** *Physical Review B*

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# Dispersive measurement



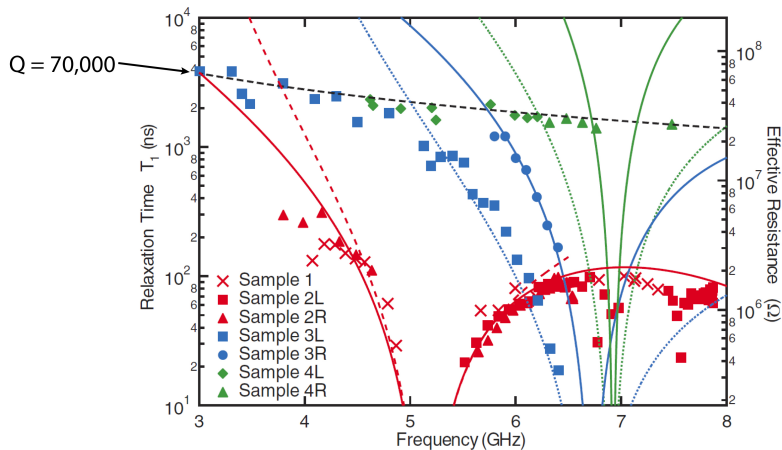
$$\text{Two-level: } \widetilde{\omega}_{Cav} = \omega_{Cav} \pm \frac{g^2}{\Delta_{01}}$$

$$\text{Three-level: } \widetilde{\omega}_{Cav} = \omega_{Cav} \pm \left( \frac{g^2}{\Delta_{01}} - \frac{g^2}{\Delta_{12}} \right) = \omega_{Cav} \pm \frac{g^2}{\Delta_{01}} \left( 1 + \frac{\Delta_{01}}{\alpha} \right)^{-1}$$

$$\Delta_{01} \gg g, \quad \Delta_{01} = \omega_{01} - \omega_{Cav}, \quad \Delta_{12} = \omega_{12} - \omega_{Cav}$$

J. Koch et al, **Charge-insensitive qubit design from the Cooper pair box** *Physical Review A* **76** 042319 2007  
Frederick W. Strauch, **Quantum logic gates for superconducting resonator qubits** *Physical Review A* **84** 052313 2011

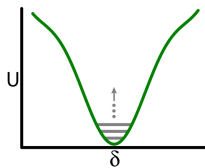
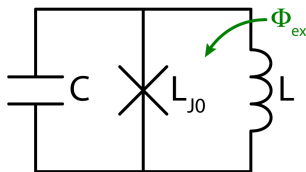
# The Purcell effect



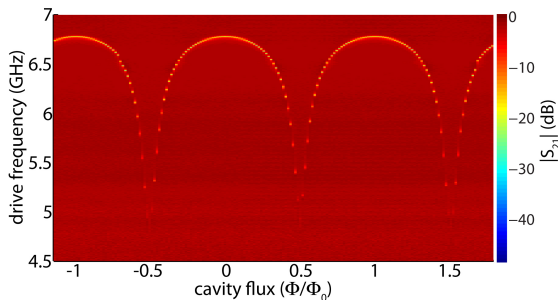
$$T_1 = \frac{1}{\gamma_P + \gamma_{Qu}}, \quad \gamma_P = \frac{2\pi f_{Cav}}{Q_{Cav}} \frac{g^2}{\Delta_{01}^2}, \quad \gamma_{Qu} = 1/T_{Qu}$$

A. A. Houck et al, **Controlling the Spontaneous Emission of a Superconducting Transmon Qubit** *Physical Review Letters* 101 080502 2008

# The tunable cavity

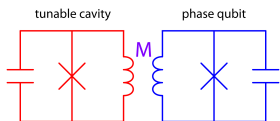
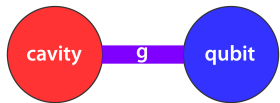


$$L/L_{J0} < 1.0$$



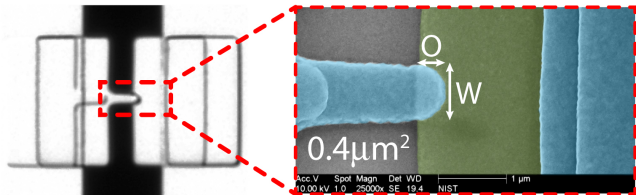
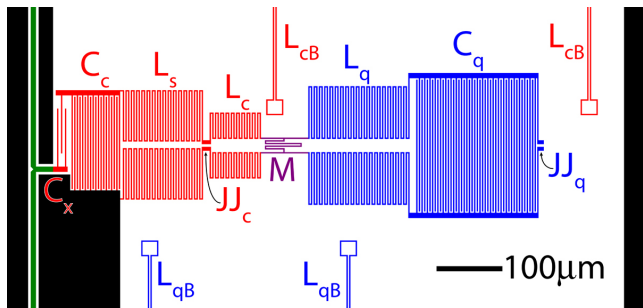
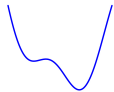
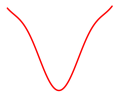
$$\begin{aligned} f_{max} &= 6.78 \text{ GHz} \\ Q_{Cav} &= 280 \\ T_{Cav} &= \frac{Q_{Cav}}{\omega_{Cav}} = 6.5 \text{ ns} \\ Q_{int} &= 8970 \\ Q_{ext} &= 290 \end{aligned}$$

# The device



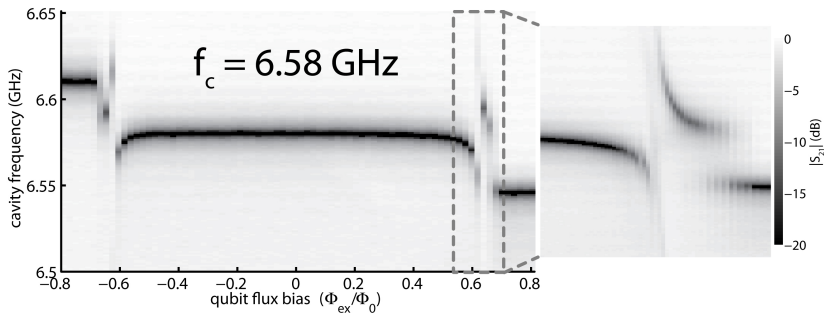
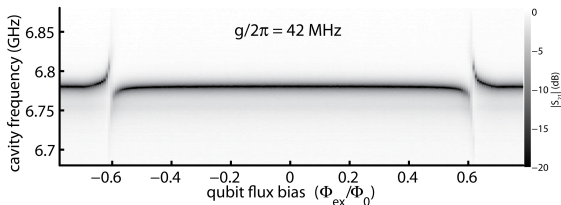
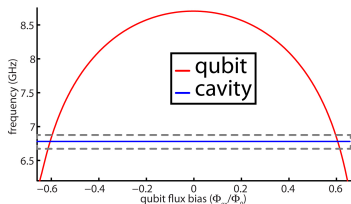
$$L/L_{j0} = 0.8$$

$$L/L_{j0} = 3.0$$

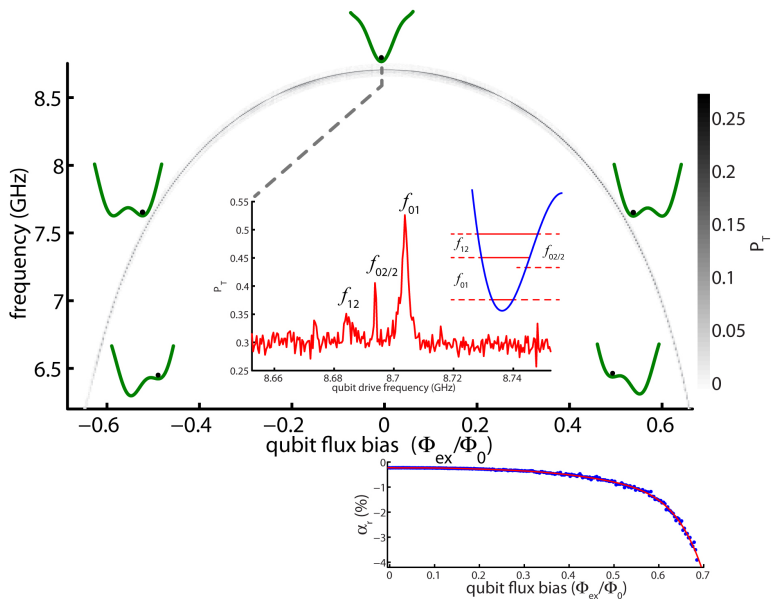




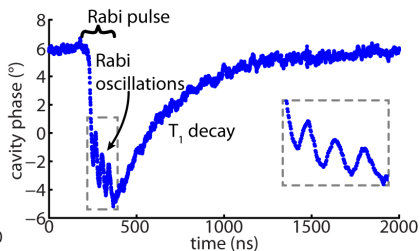
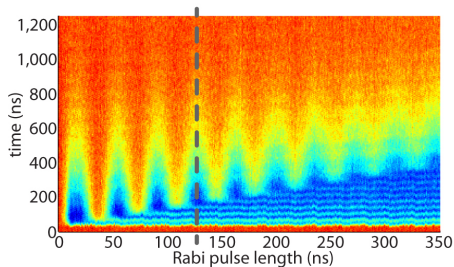
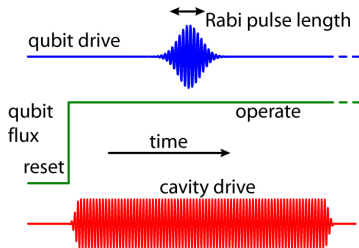
# Cavity spectroscopy



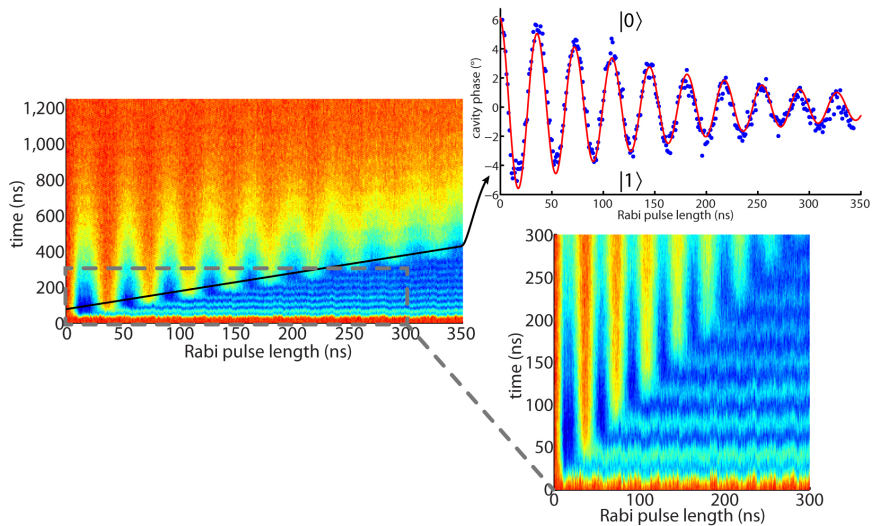
# Qubit spectroscopy



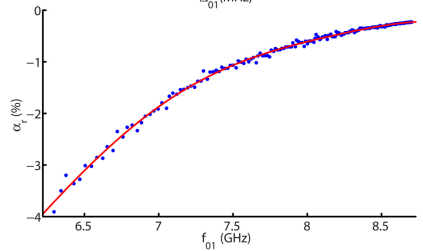
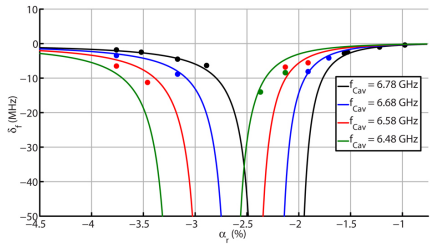
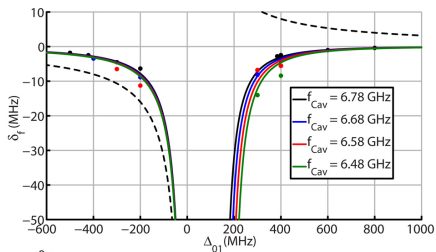
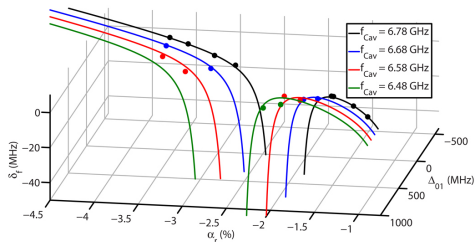
# Rabi oscillations



# Rabi oscillations

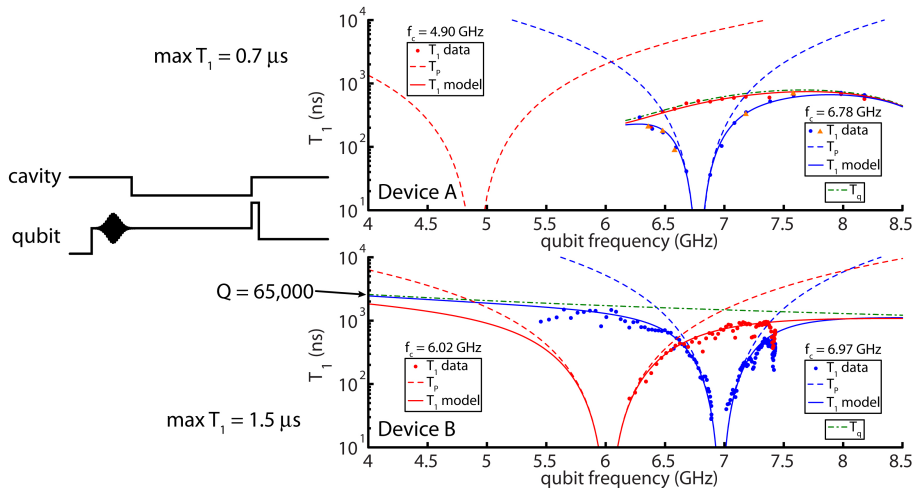


# Dispersive shifts



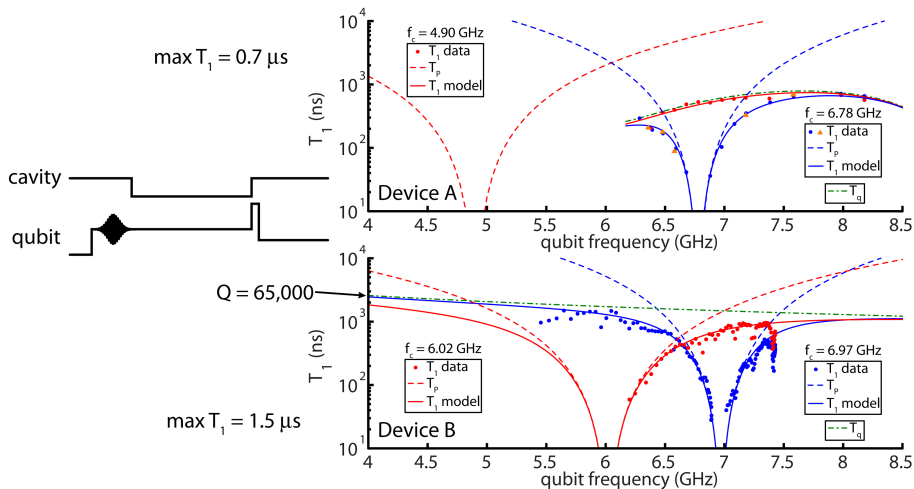
$$\delta_f = 2 \frac{g^2}{\Delta_{01}} \left( 1 + \frac{\Delta_{01}}{\alpha} \right)^{-1}$$

# The Purcell effect



$$T_1 = \frac{1}{\gamma_P + \gamma_{Qu}}, \quad \gamma_P = \frac{2\pi f_{Cav}}{Q_{Cav}} \frac{g^2}{\Delta_{01}^2}, \quad \gamma_{Qu} = 1/T_{Qu}$$

# The Purcell effect



K. Geerlings et al, **Improving the quality factor of microwave compact resonators by optimizing their geometrical parameters** *APL* **100** 192601 2012

# Conclusions

## Summary

- Designed and fabricated a long-lifetime phase qubit
- Dispersively measured a phase qubit
- Observed and changed Purcell effect with tunable cavity

## Future work

- Design improvements
- Perform bifurcation measurement, compare to tunneling measurement
- Swap cavity and qubit roles in one device; exploit tunable anharmonicity
- Multiplex multiple devices