Prominent Loss Mechanisms in Superconducting Qubits

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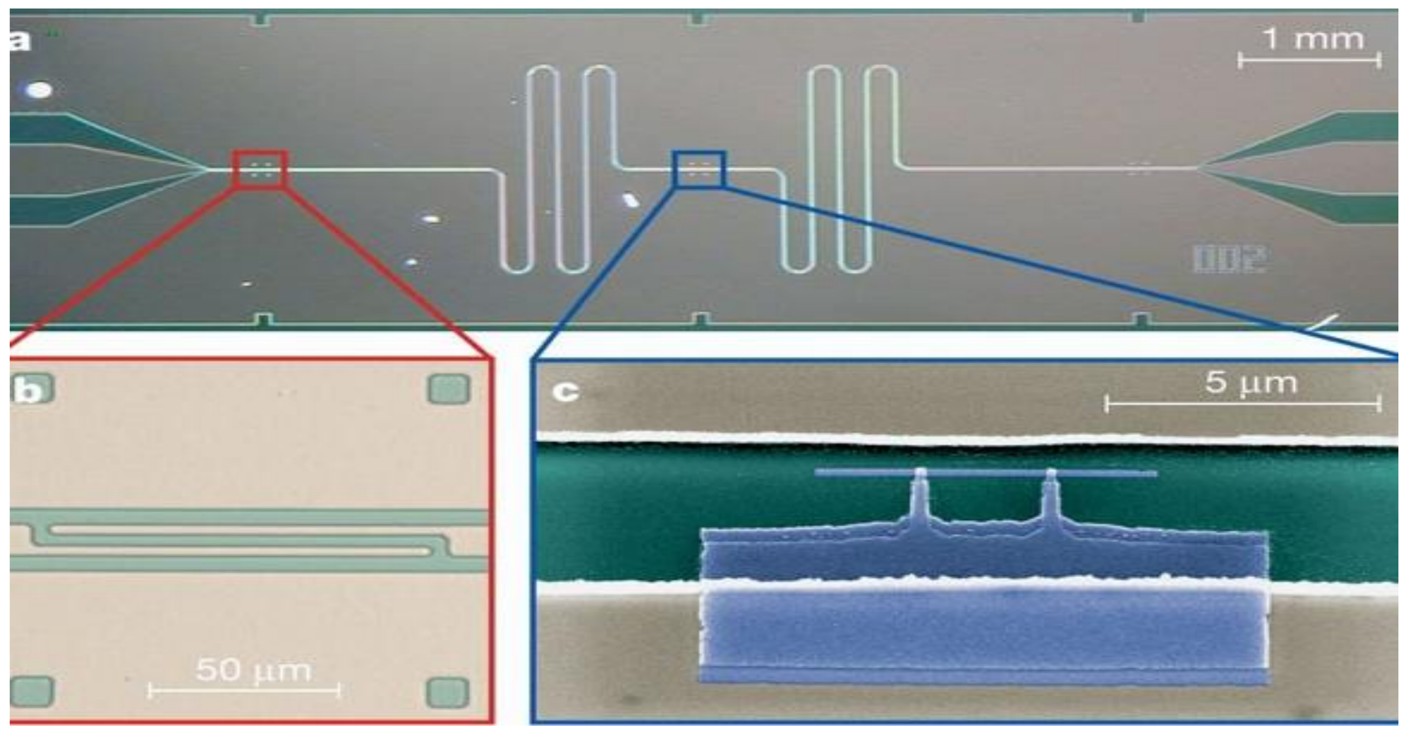
Motivation

In recent years, **superconducting qubits** have become the primary candidate for **quantum computing applications**, yet an increase in **coherence time** is necessary to exploit the full potential of this technology.

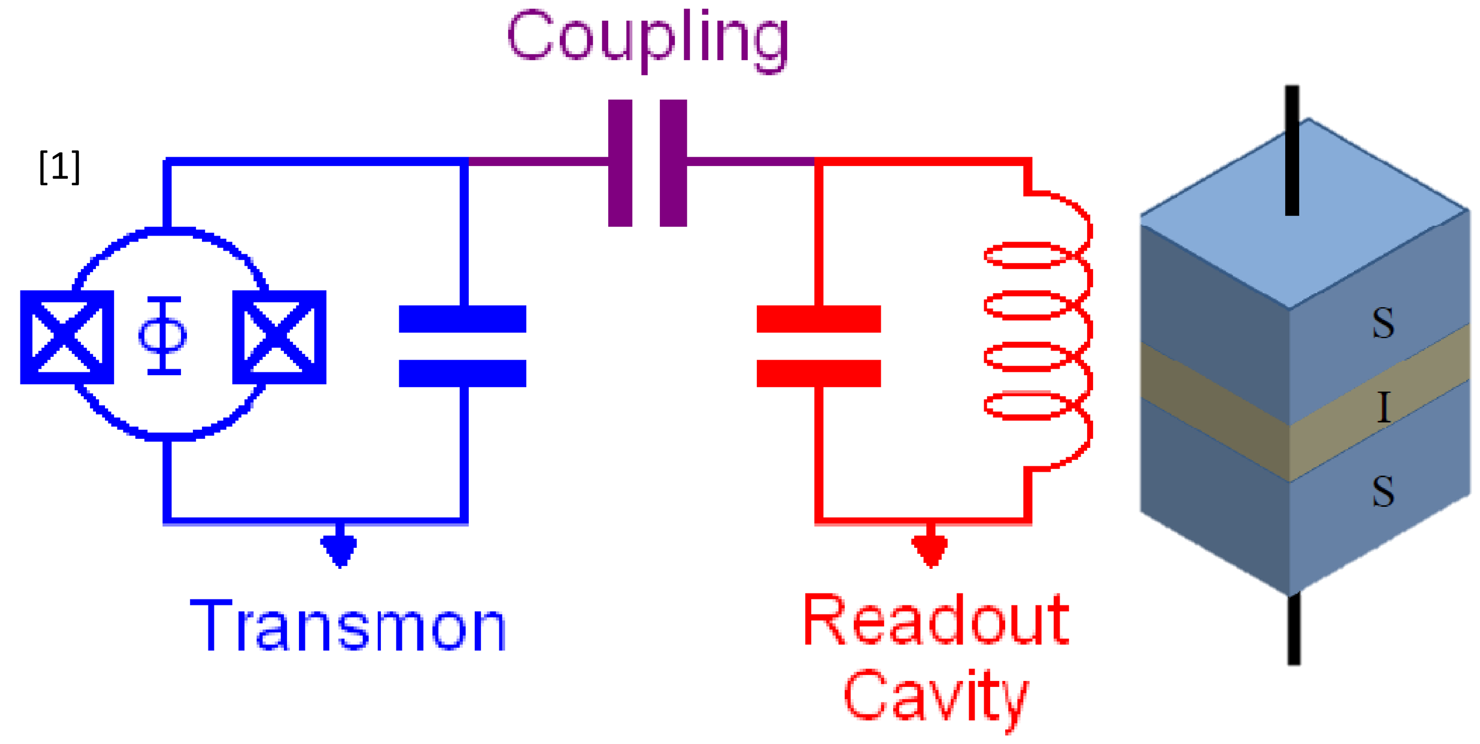
What limits coherence time is noise, which prominently arises from **QP tunneling and TLS**. Moreover, a subgroup of TLSs with different properties to traditional TLS have recently been identified by de Graaf et al.



a) Example of a Cooper Pair Box superconducting qubit. b) Readout cavity. C) Josephson Junction.

LC Circuits as Superconducting Qubits

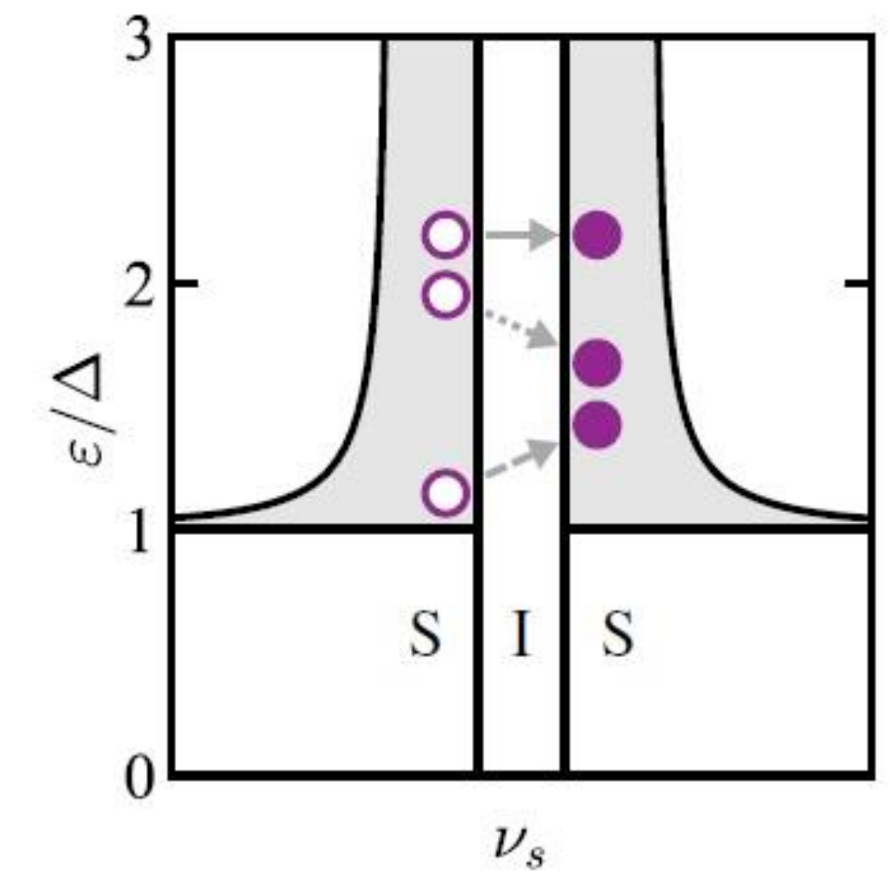
- Energy levels must be individually addressable
- Josephson Junctions, a non-dissipative and non-linear inductance
- Shunting the circuit with a large enough capacitance such that $E_c = e^2/2C$ is significantly reduced



- Circuit diagram of transmon qubit capacitively coupled to a resonator readout cavity. Transmons also allow you to use a SQUID loop by connecting two JJs (shown as Xs) in parallel.

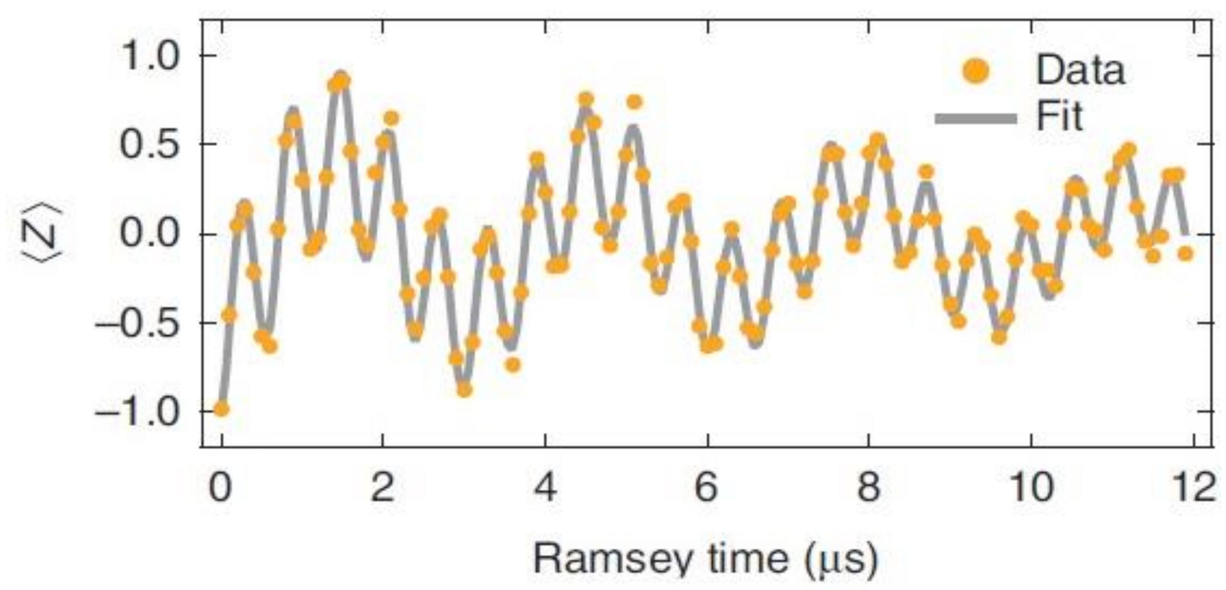
Quasiparticles (QPs)[2]

- QP tunneling across the JJ is can cause qubit excitation or relaxation

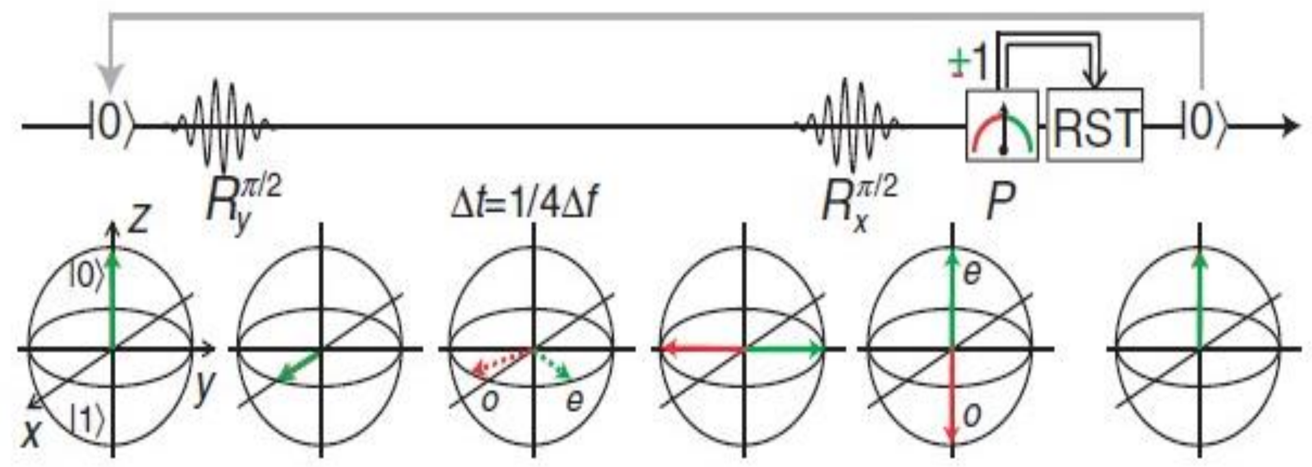


- QP tunneling mechanisms causing qubit relaxation, excitation and interband transitions

Charge Parity Detection [3]

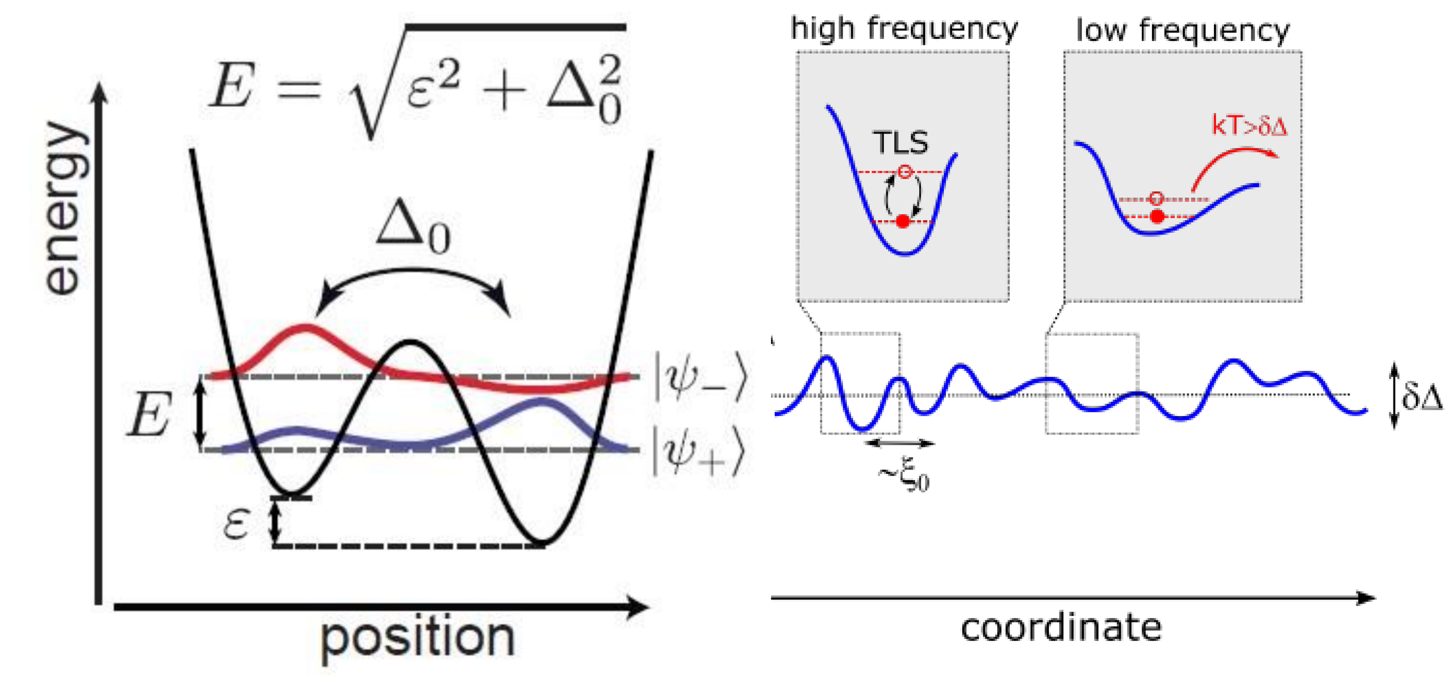


- Ramsey interferometry showing two decaying sinusoids.



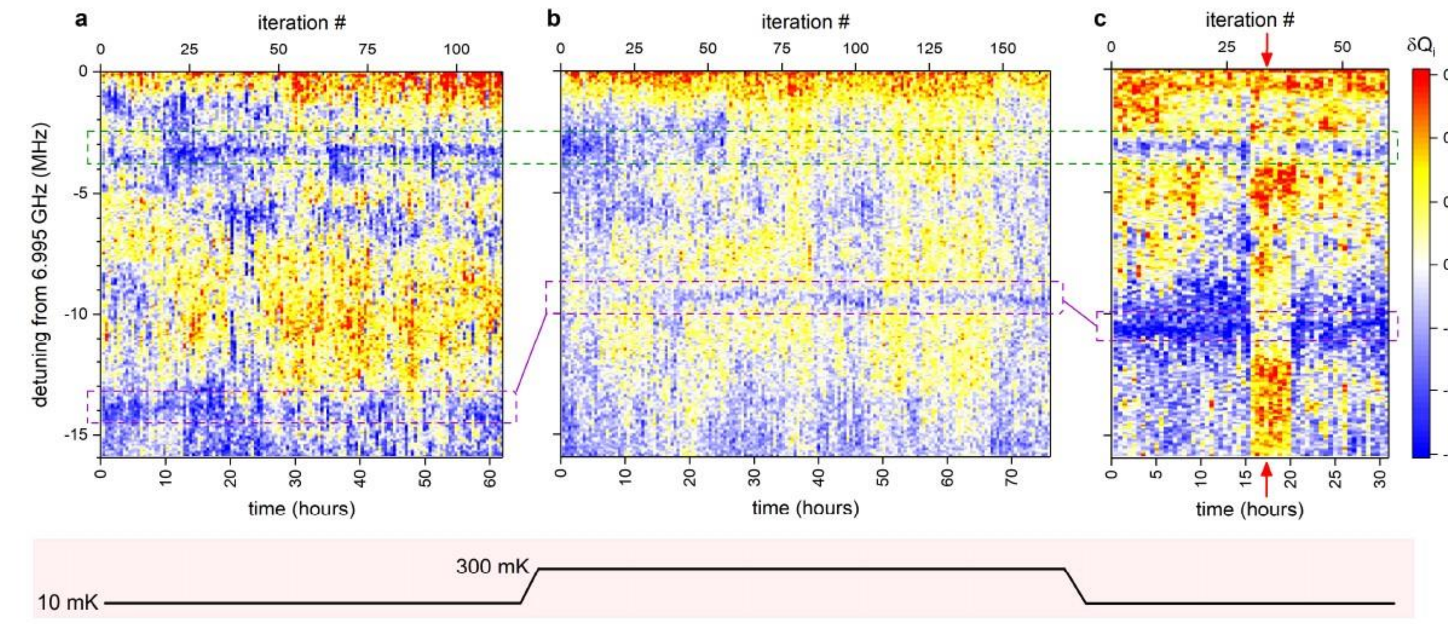
- Ramsey-type sequence which maps odd/even charge parity to qubit ground/excited state

Two-level Systems (TLS)[4]



- TLS according to Standard Tunneling Model (STM) (left) and subgroup identified by de Graaf et al (right)

Identification of Quasiparticle TLS



- Spectral and temporal mapping of quality factor at 10mK-300nK-10mK

References

[1] Geerlings, Kurtis Lee. *Improving coherence of superconducting qubits and resonators*. Yale University, 2013.

[2] Serniak, K., et al. "Hot nonequilibrium quasiparticles in transmon qubits." *Physical review letters* 121.15 (2018): 157701.

[3] Ristè, D., et al. "Millisecond charge-parity fluctuations and induced decoherence in a superconducting transmon qubit." *Nature communications* 4.1 (2013): 1-6.

[4] de Graaf, S. E., et al. "Two-level systems in superconducting quantum devices due to trapped quasiparticles." *arXiv preprint arXiv:2004.02485* (2020).

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