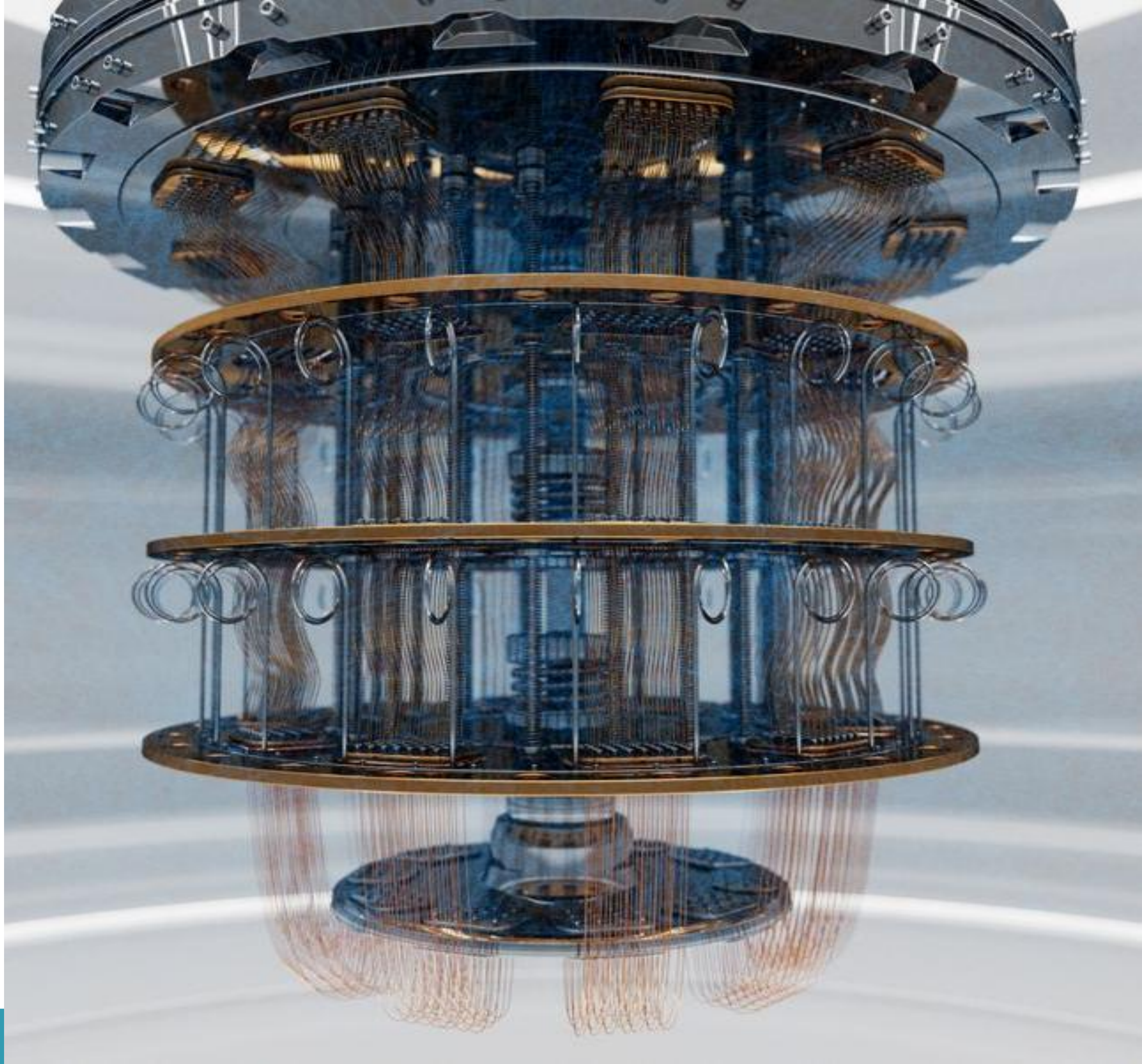
Understanding Quantum Noise

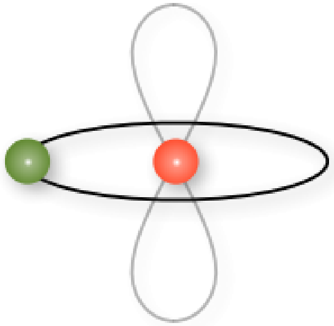
Based on : A Quantum Engineer's Guide To Superconducting Qubits

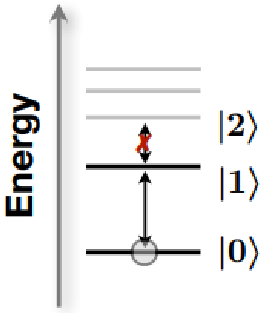
Appl. Phys. Rev. 6, 021318 (2019)

Prepared by: Albaraa Shafi



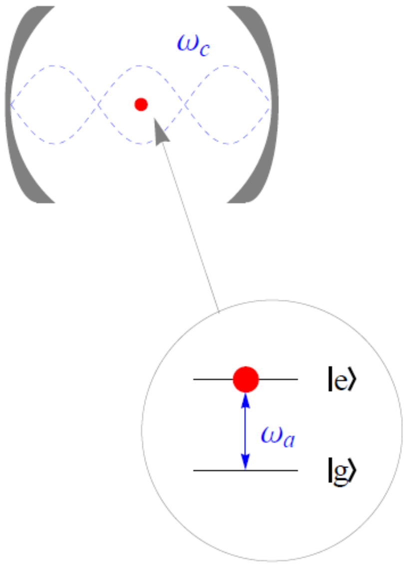
Qubits and Hamiltonians





Good «two-level atom» approximation

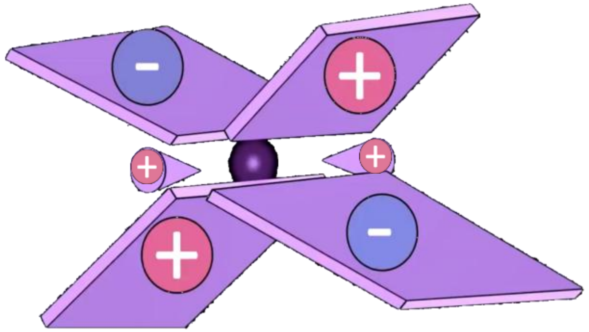
$$E_{01} = E_1 - E_0 = \hbar\omega_{01}$$

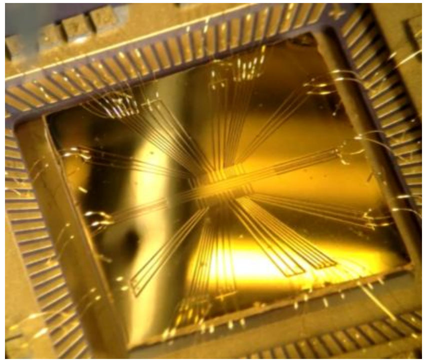


Jaynes-cummings Hamiltonian

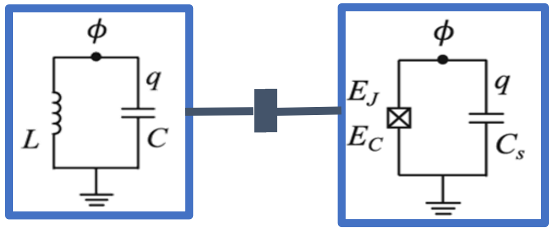
$$H_{\mathrm{JC}} = \omega_r\left(a^\dagger a + \frac{1}{2}\right) + \frac{\omega_{\mathrm{q}}}{2}\sigma_z + g\left(\sigma_+ a + \sigma_- a^\dagger\right)$$

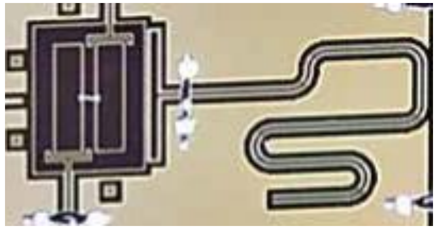
Ion Traps





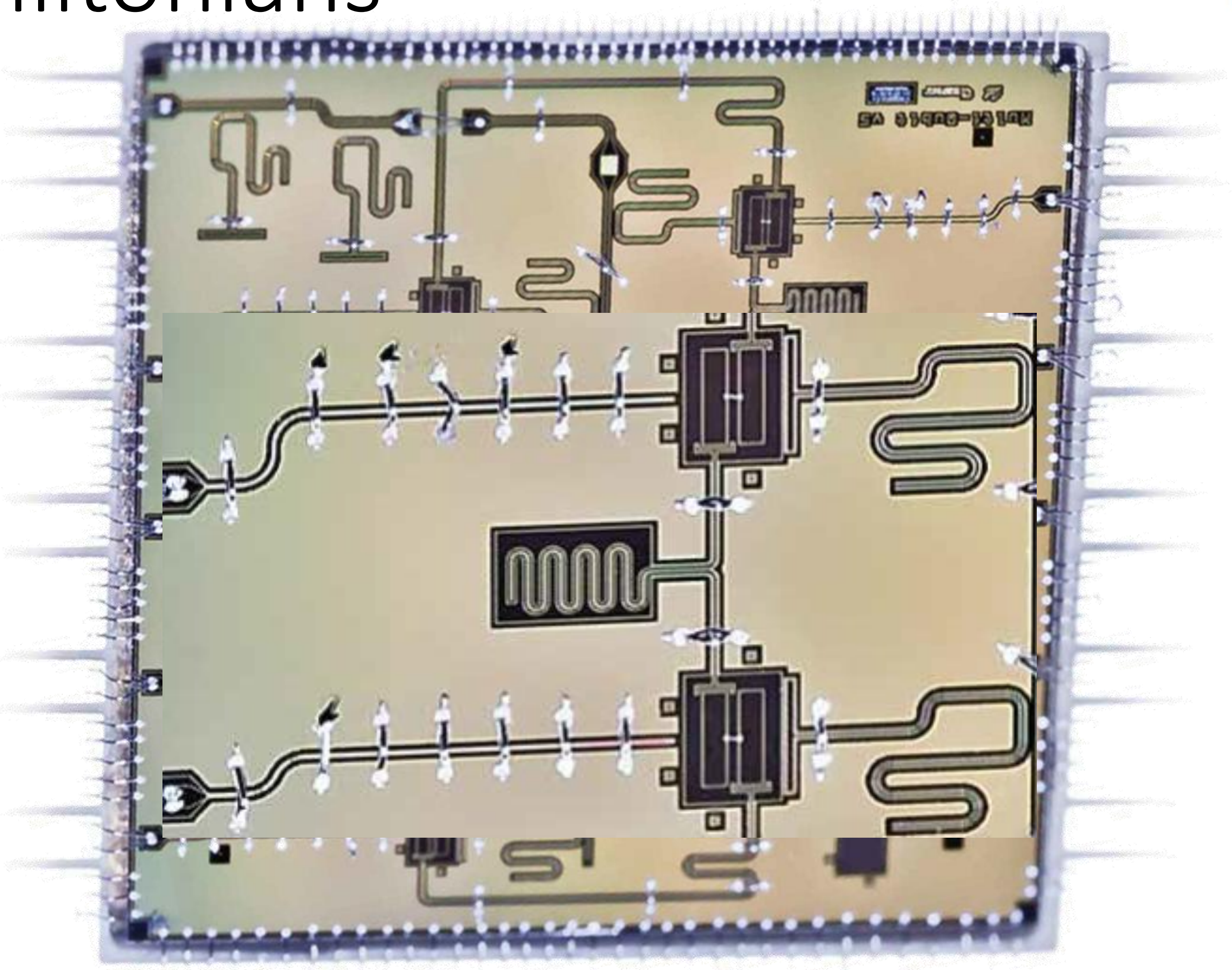
Superconducting Circuits





Qubits and Hamiltonians

Adding
communication
lines/links
=
Adding noise
channels!



Open Quantum Systems

Open Quantum Systems

- Schrodinger Equation: $$i\hbar\frac{\partial}{\partial t}\Psi = \hat{H}\Psi$$ Pure States (Closed Systems)
- Von Neuman Equation: $$\dot{\rho}_{\text{tot}}(t) = -\frac{i}{\hbar}[\boxed{H_{\text{tot}}}, \rho_{\text{tot}}(t)]$$ Pure States (Closed System)

$$\boxed{H_{\text{tot}} = H_{\text{sys}} + H_{\text{env}} + H_{\text{int}}}$$

- Linbald master Equation: Mixed States (Open System)

$$\dot{\rho}(t) = \boxed{-\frac{i}{\hbar}[H(t), \rho(t)]} + \boxed{\sum_n \frac{1}{2}\left[2C_n\rho(t)C_n^\dagger - \rho(t)C_n^\dagger C_n - C_n^\dagger C_n\rho(t)\right]}$$

System

Coupling to environment

Machine Gun Solution!

Modeling Noise: Bloch-Redfield Model

Pistol Solution

- Assumptions:
  - 2 level System
  - Weak system-bath coupling
  - Short correlation time
- Upside: Dissipation rates acquired from experiments.
- Downside: Can lead to unphysical density matrices outside the assumption.
- Bloch-Redfield Equation:

$$\frac{d}{dt}\rho_{ab}(t) = -i\omega_{ab}\rho_{ab}(t) + \sum_{c,d}^{\text{sec}} R_{abcd}\rho_{cd}(t)$$

$$\boxed{\begin{aligned} R_{abcd} = -\frac{\hbar^{-2}}{2}\sum_{\alpha,\beta}\Bigg\{ & \delta_{bd}\sum_n A^{\alpha}_{an}A^{\beta}_{nc}S_{\alpha\beta}(\omega_{cn}) - A^{\alpha}_{ac}A^{\beta}_{db}S_{\alpha\beta}(\omega_{ca}) \\ & + \delta_{ac}\sum_n A^{\alpha}_{dn}A^{\beta}_{nb}S_{\alpha\beta}(\omega_{dn}) - A^{\alpha}_{ac}A^{\beta}_{db}S_{\alpha\beta}(\omega_{db})\Bigg\}, \end{aligned}}$$

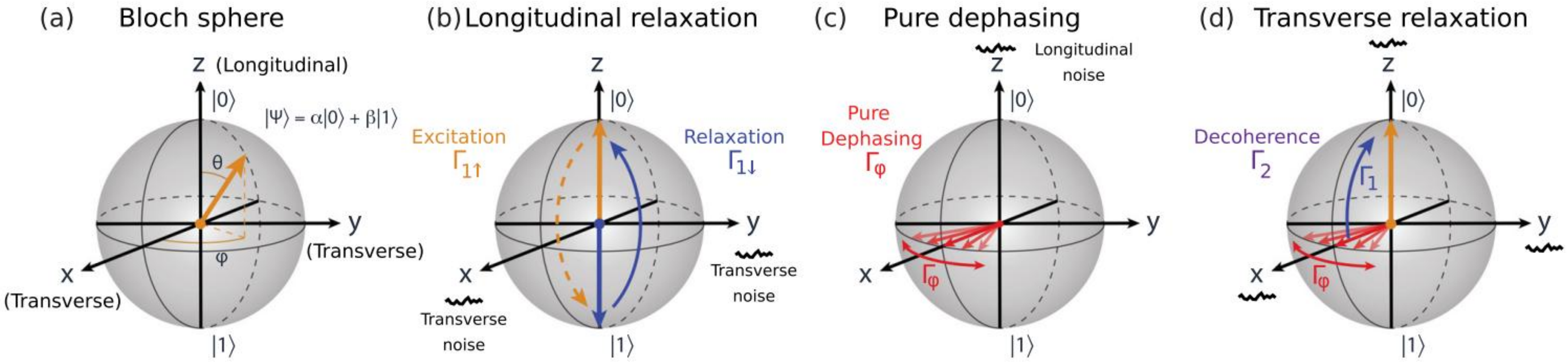
Modeling Noise: Bloch-Redfield Model

Closed System

$$\begin{pmatrix} |\alpha|^2 & \alpha\beta^* \\ \alpha^*\beta & |\beta|^2 \end{pmatrix}$$

Open System

$$\begin{pmatrix} 1 + (|\alpha|^2 - 1)e^{-\Gamma_1 t} & \alpha\beta^* e^{i\delta\omega t} e^{-\Gamma_2 t} \\ \alpha^* \beta e^{-i\delta\omega t} e^{-\Gamma_2 t} & |\beta|^2 e^{-\Gamma_1 t} \end{pmatrix}.$$



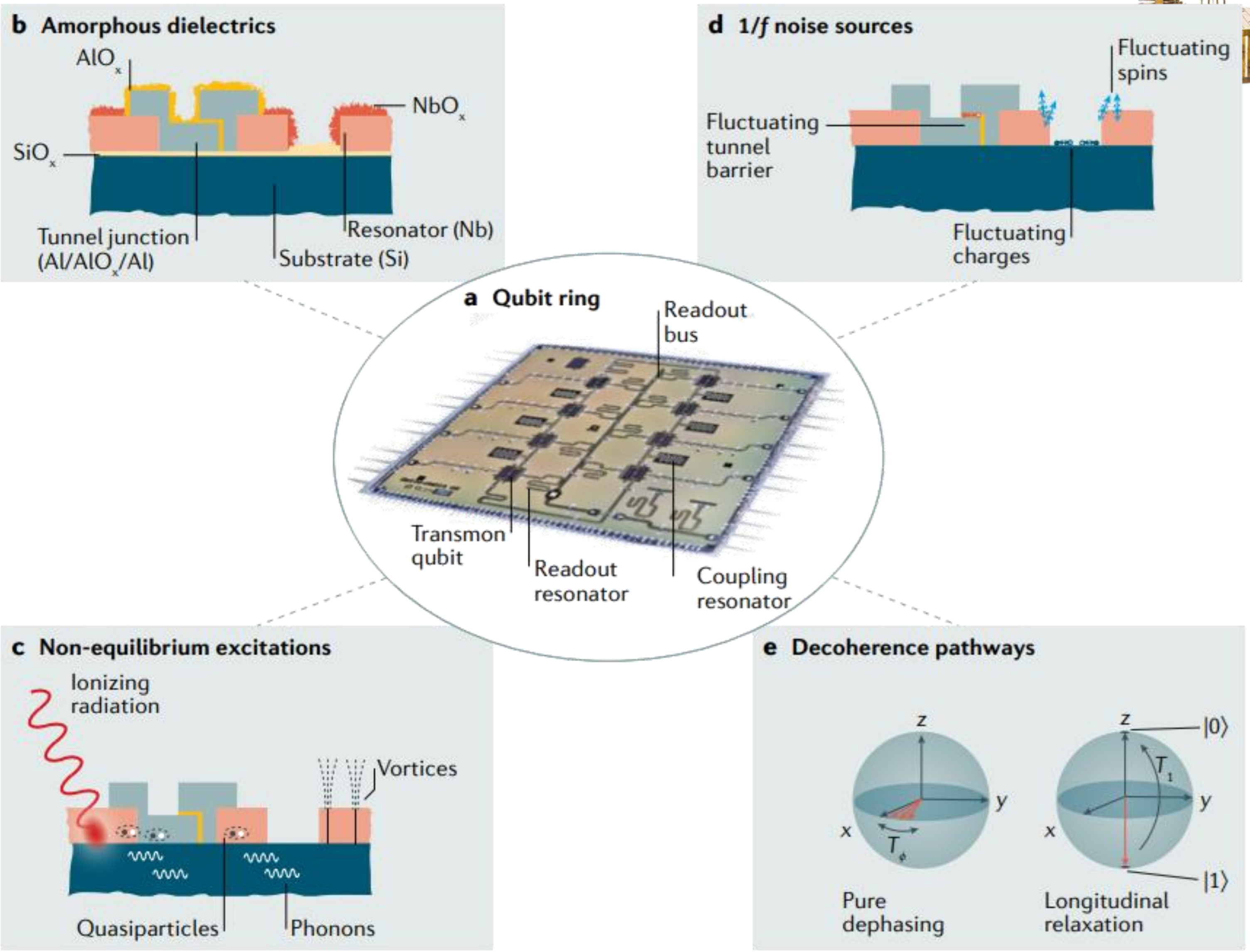
Types of Noise

Systematic Noise:

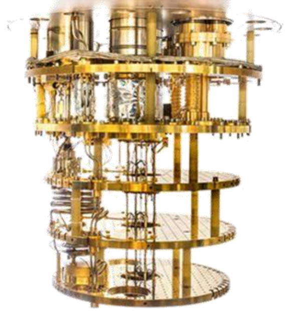
Can be engineered and fixed

Stochastic Noise:

Need to be understood



Discussion Points



- Is qubit representation best for superconducting qubits? Or do we need to consider higher states?
- What is the more relevant decay quantity, T1 or T2? If T2, do we represent with T2* or T2E?
- How to differentiate between different types of stochastic noise? What experiments can be done to isolate different noise sources?
- What are the best ways to tackle quantum noise? Design? Fabrication? Control? Postprocessing?

Superconducting Qubits