Universität Konstanz

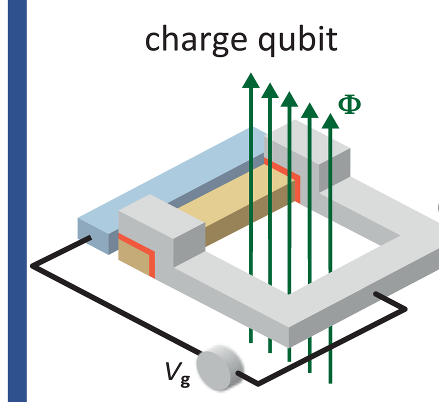
QSOLID

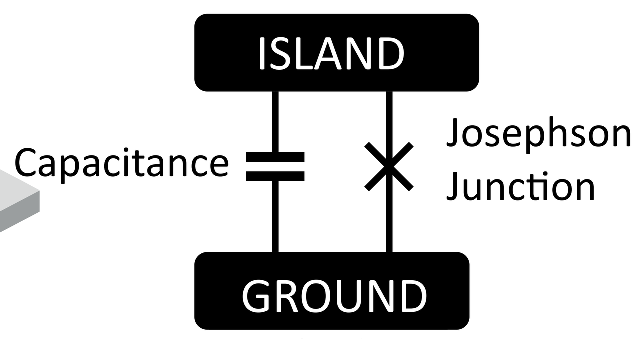
Quantum Computer in the Solid State

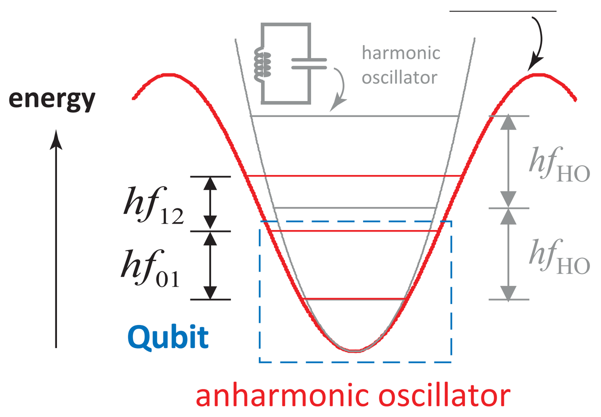
Smoking-gun signatures of non-Markovianity of a superconducting qubit

Balázs Gulácsi and Guido Burkard, Department of Physics, University of Konstanz

Prelude I – Transmons







Ref: Oliver, W. & Welander, P. , MRS Bulletin, 38(10), 816-825. (2013)

Prelude II – Markovianity

Time evolution with the dynamical map

$\rho(t) = \Lambda(t,t_0)\rho(t_0)$ ***Map needs to be CPTP!***

We adopt the definition for Markovianity as CP-divisibility:

$$\Lambda(t,t_0) = \Lambda(t,t')\Lambda(t',t_0)\ \forall t' : t_0 \le t' \le t$$

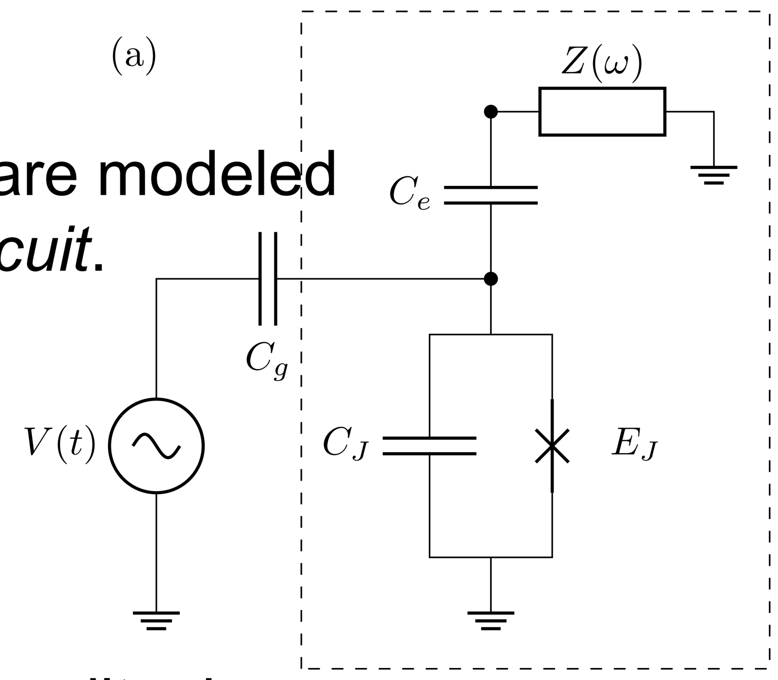
For a time-local master equation Markovianity implies the Lindblad form with non-negative rates for all times:

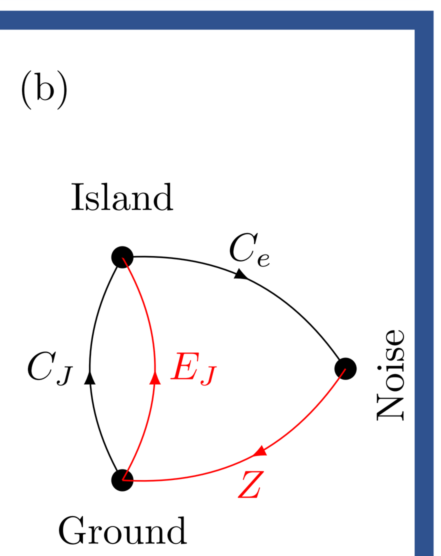
$$\dot{\rho}(t) = -i[H(t),\rho(t)] + \sum_k \gamma_k(t)\left(L_k(t)\rho(t)L_k^\dagger(t) - \frac{1}{2}\{L_k^\dagger(t)L_k(t),\rho(t)\}\right)$$

Model

Physical hardware modeled by a *lumped circuit*.

Quantum circuit theory





Open system Hamiltonian:

$$\boxed{H = -\frac{\omega_q}{2}\sigma_z - \Omega(t)\sigma_y + H_Z + \eta e\sigma_y B}$$

Driven qubit

Impedance, Caldeira-Leggett boson bath

Transverse noise $\eta = \dfrac{2C_e}{C_J + C_g + C_e}\sqrt[4]{\dfrac{E_J}{4E_C}}$

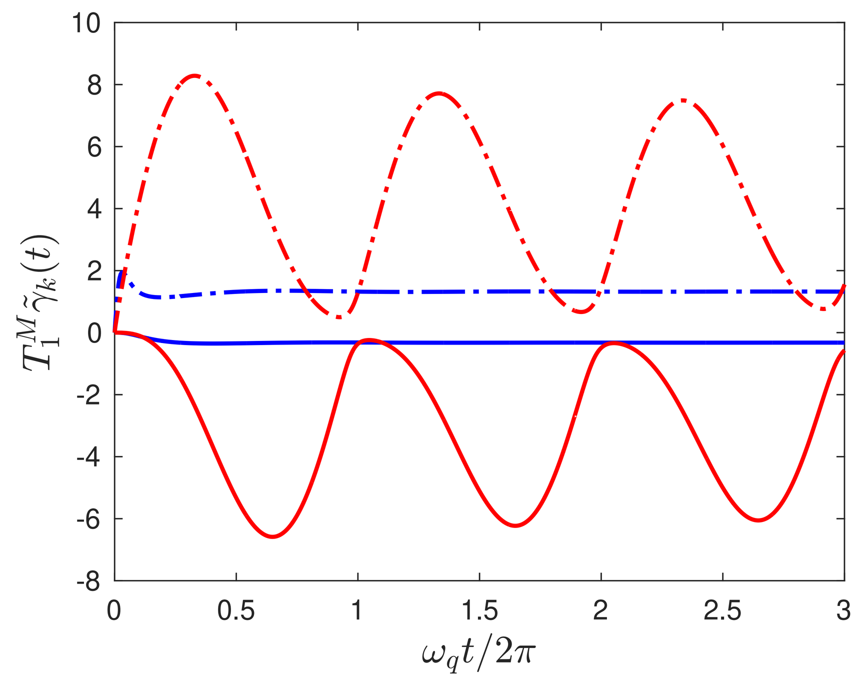
Open transmon system

We apply the time-convolutionless projection technique to the composite qubit-environment Hamiltonian

$$\dot{\rho}(t) = -i[H(t),\rho(t)] + \eta^2 \sum_{k,l=\pm} d_{kl}(t)\left(\sigma_k\rho(t)\sigma_l^\dagger - \frac{1}{2}\{\sigma_l^\dagger\sigma_k,\rho(t)\}\right)$$

Only approximation used: Born!

Decoherence matrix exhibits a negative eigenvalue for all times: *eternal non-Markovianity!*



Solution of the master equation as a dynamical map:

$$\rho(t) = \sum_{a,b} C_{ab}(t)\tau_a\rho(0)\tau_b^\dagger$$

Positve semidefinite Choi matrix – complete positivity ☑

Qubit precession

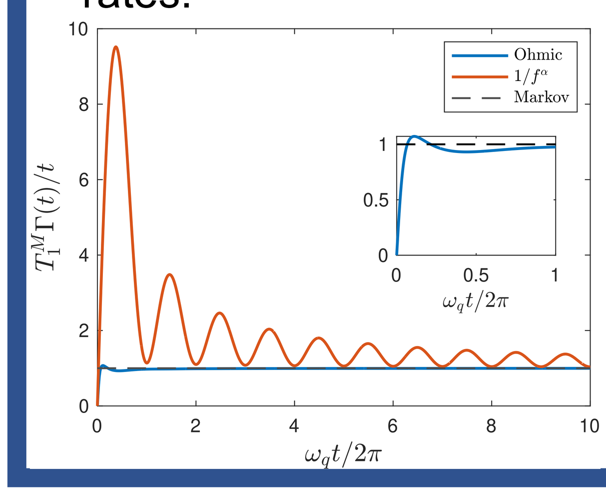
Idle qubit evolution through the expectation value

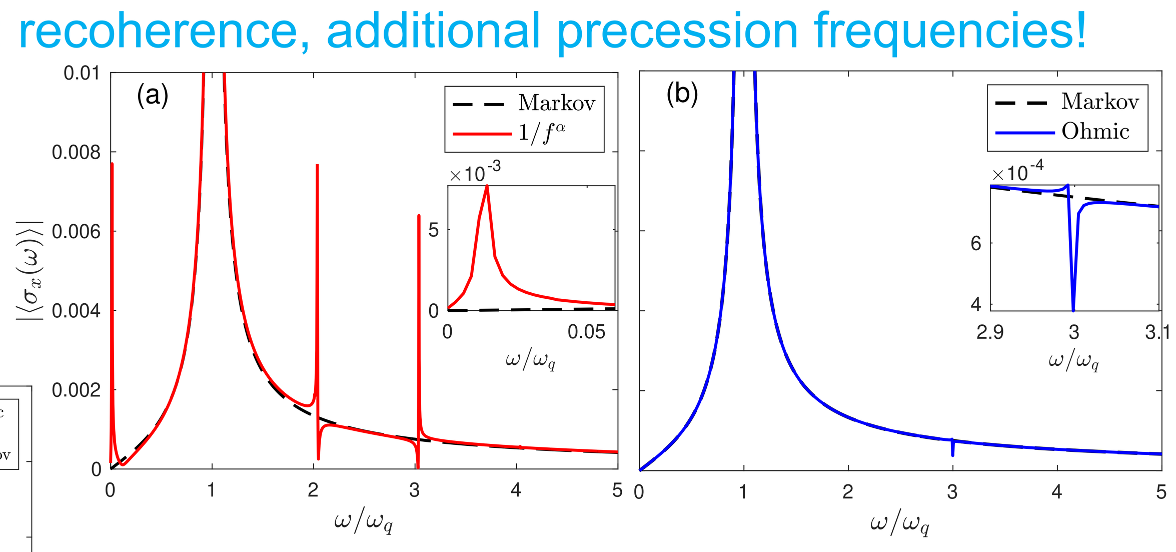
$$\langle\sigma_x(t)\rangle = 2e^{-\frac{\Gamma(t)}{2}}\mathrm{Re}\left(e^{i\varphi(t)}(\rho_{01}(0)x_+(t) + \rho_{10}(0)x_-(t))\right)$$

Markovian case: exponentially decaying precession with the qubit frequency.

Non-Markovian effects: recoherence, additional precession frequencies!

Non-exponential decay function, Periodic recoherence through negative decay rates!



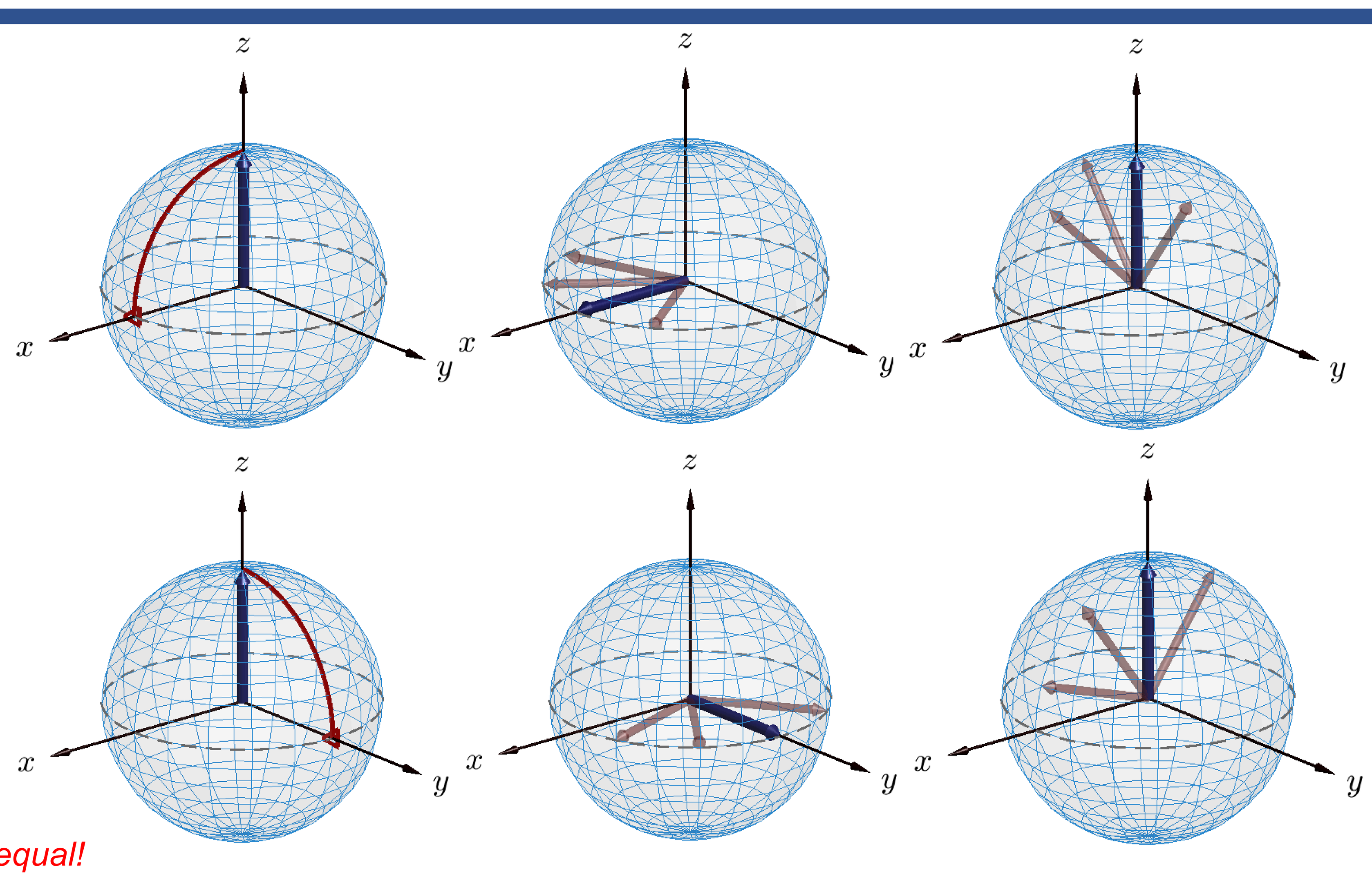


Spectral properties reveal higher harmonics in the qubit precession. Shape and height of the peaks depend on the initial condition, *memory!*

Smoking-gun experiment

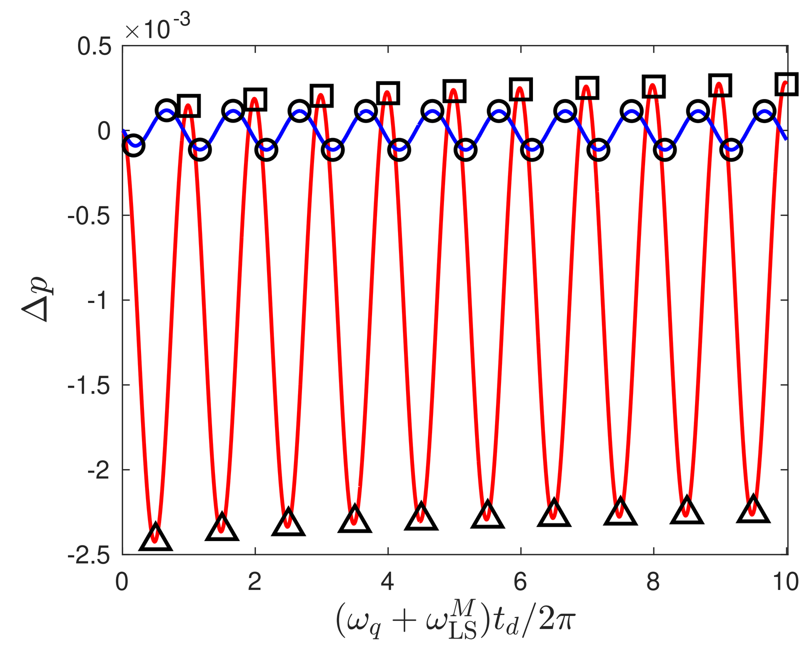
1. Initialize $|0\rangle$
2. Rotate around Y by $\pi/2$
3. Delay time t_d
4. Rotate around Y by $-\pi/2$
5. Measure state

1. Initialize $|0\rangle$
2. Rotate around X by $-\pi/2$
3. Delay time t_d
4. Rotate around X by $\pi/2$
5. Measure state



Markovian expectation: probability of measuring 0 is equal!

Imbalance of probabilites due to non-Markovianity



For a transmon qubit with $T_2 \approx 10\mu s$

SPONSORED BY THE
Federal Ministry of Education and Research

The QSolid project acknowledges the support of the Federal Ministry of Education and Research (BMBF) within the framework programme "Quantum technologies – from basic research to market" (Grant No. 13N16167).