Quantum dynamics of simultaneously measured non-commuting observables

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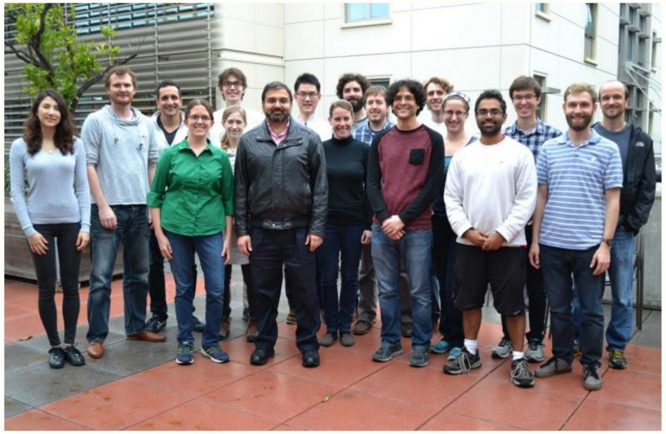

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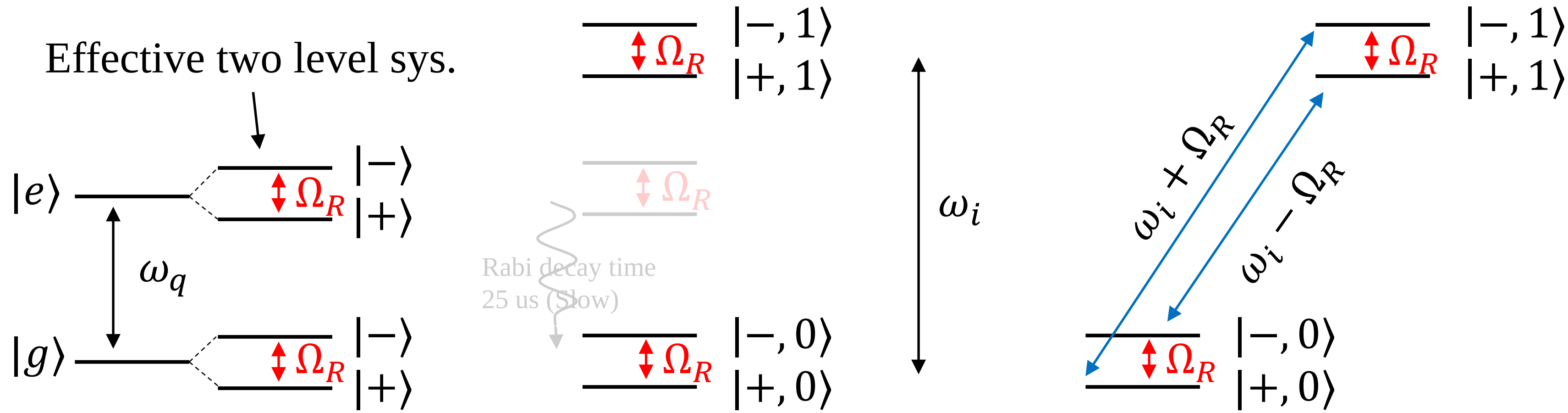
Paper Intro.

- Quantum non-demolition(QND) measurement of non-commuting observables
- Show that the uncertainty principle governs the dynamics of the wave function
- Quantum state tomography by keeping track measurement record

Application: Quantum control

- Rapid state purification, adaptive measurement, measurement-based state steering and continuous quantum error correction

Level structure and single quadrature measurement (SQM)



Qubit | Qubit ⊗ Rabi drive | Qubit ⊗ Rabi drive ⊗ Cavity | Qubit ⊗ Rabi drive ⊗ Cavity + Sideband

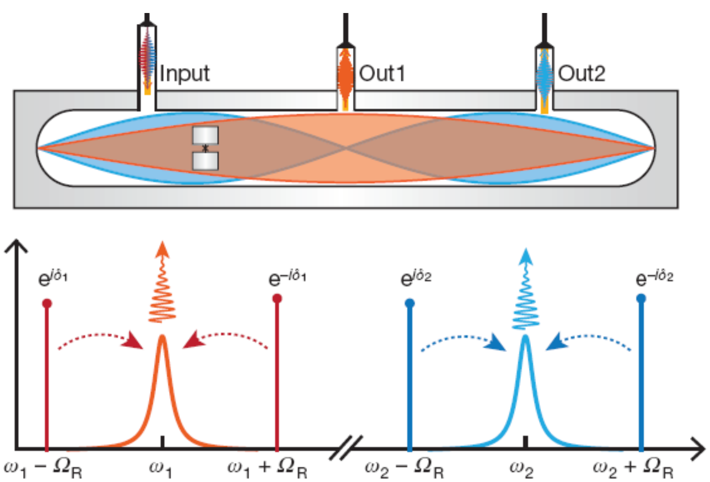
$$H_{\mathrm{eff}} = \frac{\chi \bar{a}_0}{2}\Big[\underbrace{a\sigma^\dagger e^{i\delta} + a^\dagger \sigma e^{-i\delta}}_{\text{Resonant heating}} + \underbrace{a\sigma e^{-i\delta} + a^\dagger \sigma^\dagger e^{i\delta}}_{\text{Resonant cooling}}\Big]$$

$$= \frac{\chi \bar{a}_0}{2}(a + a^\dagger)\sigma_\delta$$

$$\sigma_\delta \equiv \sigma_x \cos\delta + \sigma_y \sin\delta.$$

Note. Hamiltonian of cavity under classical field Ω

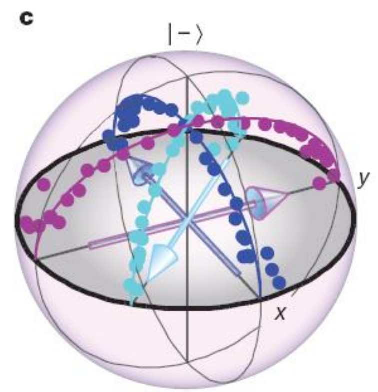
$$\mathrm{H} = \Omega(a + a^\dagger)$$

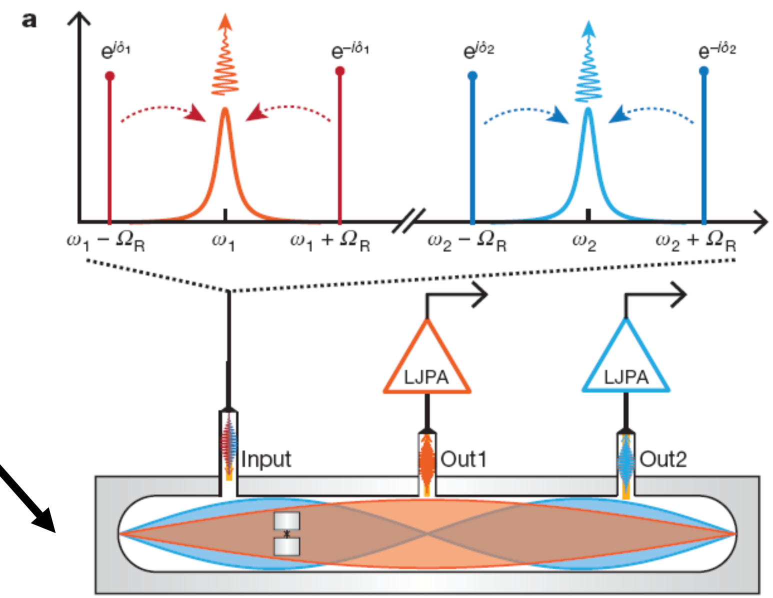


Experimental setup and SQM

- To demonstrate control of the measurement axis, perform a SQM.
- After SQM, tomography confirms the measurement axis.
- By using two different modes of the cavity, observing two different quadrature is possible.

Measurement = Projection

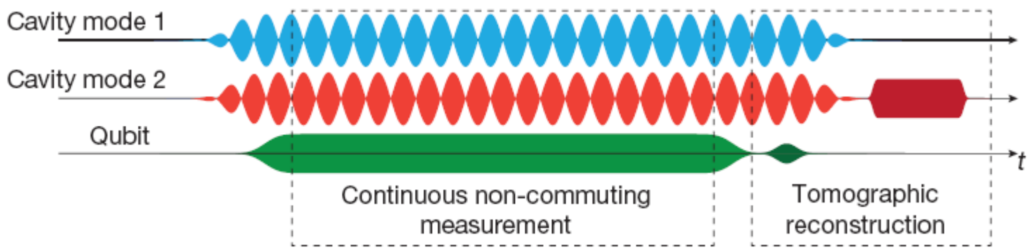


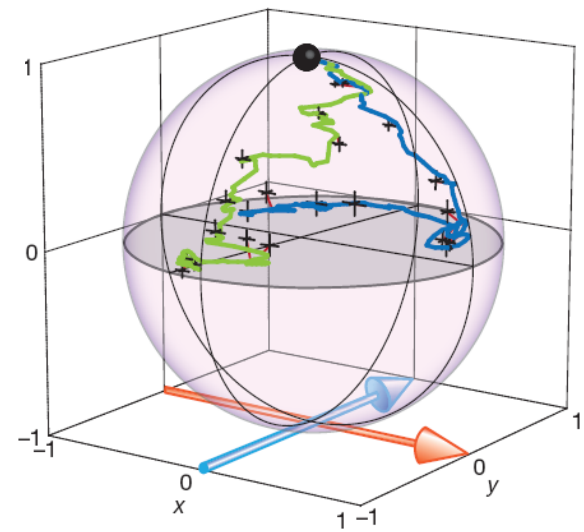


$$(\omega_q, \omega_1, \omega_2) = 2\pi \cdot (4.262, 6.666, 7.391)\ GHz$$

State tracking and initial state reconstruction

c

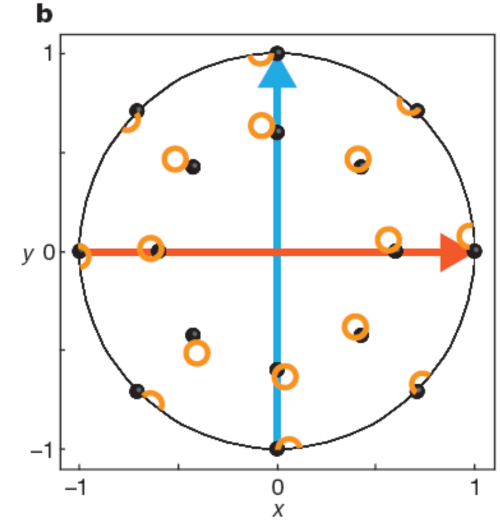




- Continuously measure two non-commuting observables => track quantum trajectories

- Using large sets of trajectories of non-commuting observables, reconstruct the initial state(maximum likelihood estimation).

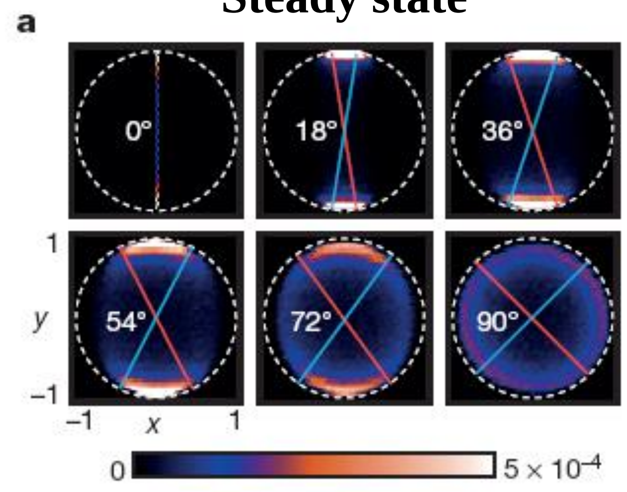
b



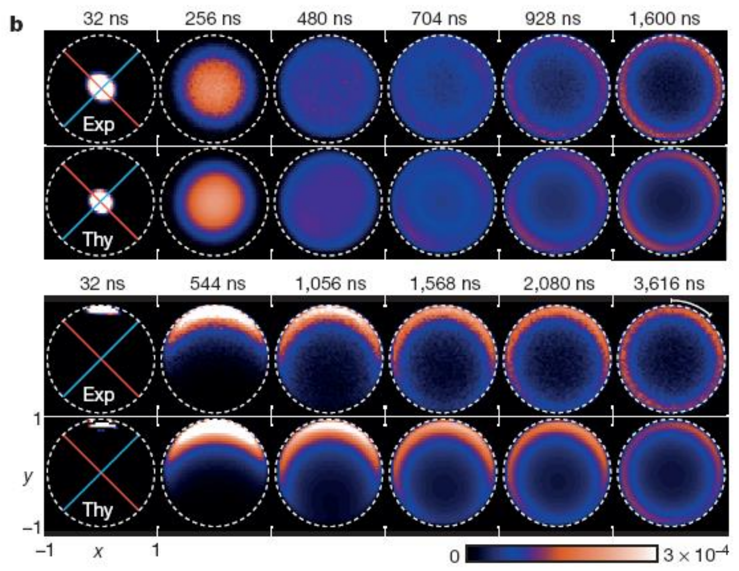
Beyond the usual wavefunction collapse

- If the measurement axis is orthogonal, then the state do not collapse to any point.
- Angular probability distribution diffuses in time.

Steady state



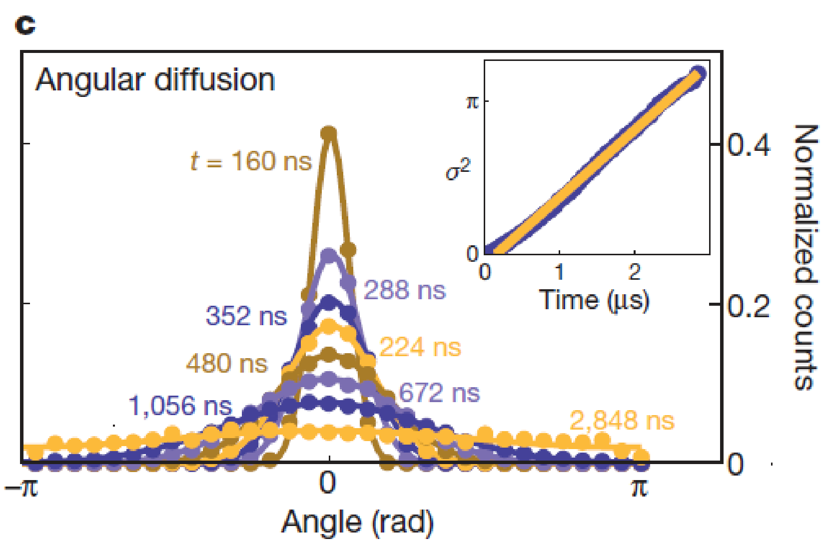
Function of time



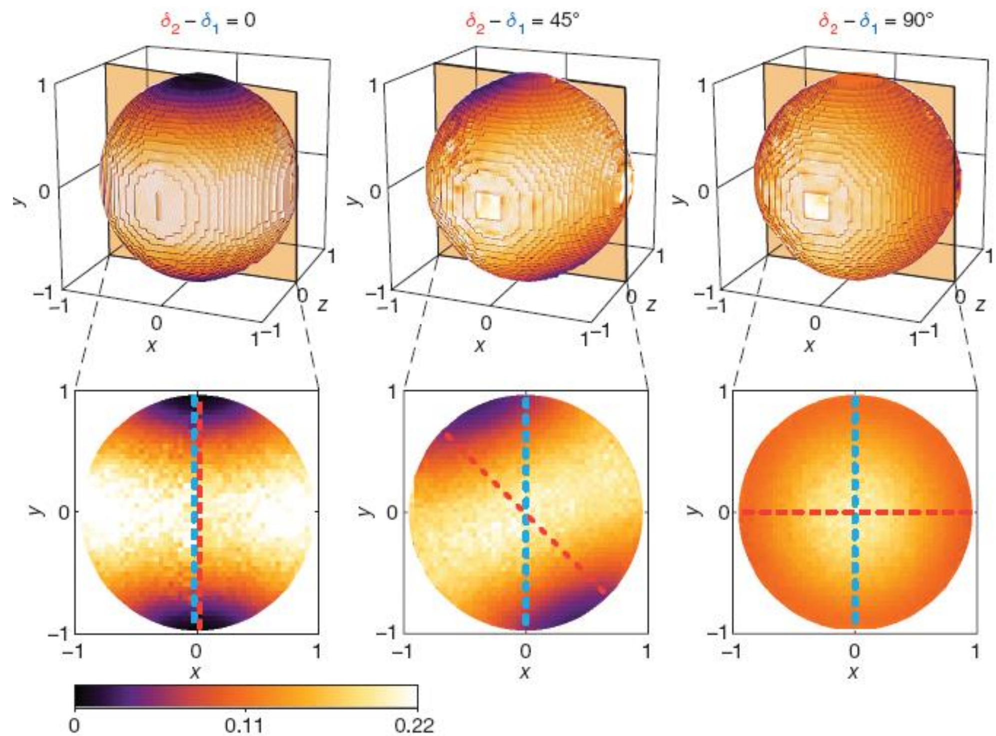
Persistent diffusion

- The system continues to evolve even probability distributions have reached steady state. => Persistent diffusion

$$\mathrm{Tr}[\mathrm{d}\rho^{\dagger}\mathrm{d}\rho] = (\Delta\sigma_{\delta,1}^{2}\Gamma_1\eta_1 + \Delta\sigma_{\delta,2}^{2}\Gamma_2\eta_2)\mathrm{d}t \geq |\langle[\sigma_{\delta_1},\sigma_{\delta_2}]\rangle|\sqrt{\eta_1\eta_2\Gamma_1\Gamma_2}\,\mathrm{d}t$$



Magnitude of quantum back-action



Q&A

Q. How the measurement can be done without the state collapse?

A. Actually, the state interacting with measurement device collapses. However, because the atomic state is not directly measured, atomic state remains un-collapsed.(Photon number is collapsed)