Superconducting Circuits for Quantum Information

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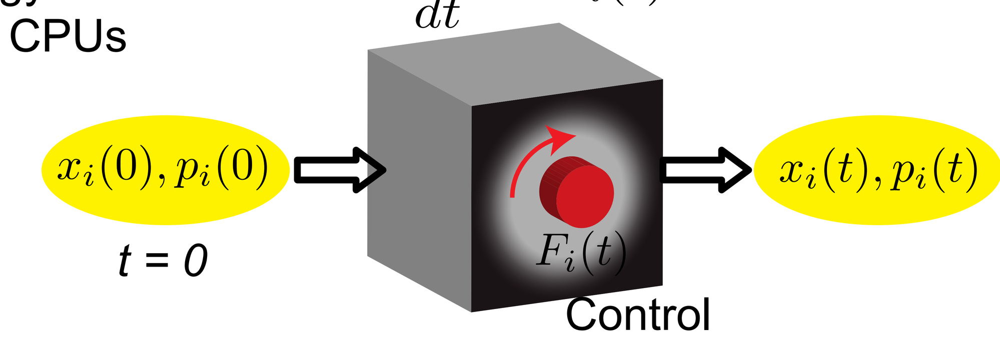
Quantum Information

Experimental quantum information:
a fast-developing field where we directly manipulate the quantum state of isolated systems based on the Schrodinger equation.

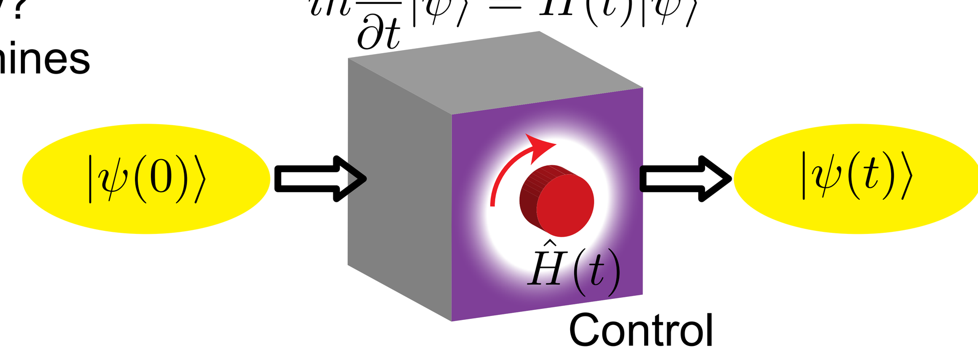
Current technology
-- from rocket to CPUs

$$\frac{dp_i}{dt} = F_i(t)$$

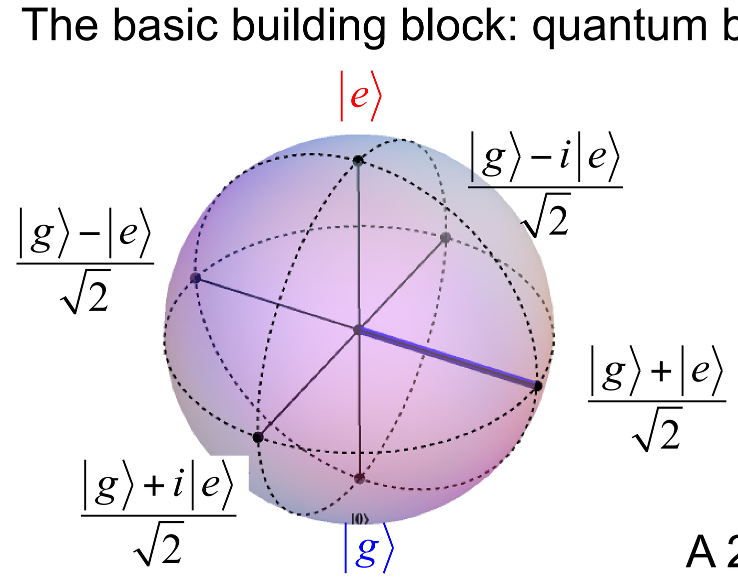


Future technology?
-- Quantum machines

$$i\hbar\frac{\partial}{\partial t}|\psi\rangle = \hat{H}(t)|\psi\rangle$$



The basic building block: quantum bit



One qubit:
$$|\psi\rangle = C_1|g\rangle + C_2|e\rangle$$

Two qubit:
$$|\psi\rangle = C_{11}|gg\rangle + C_{12}|ge\rangle + C_{21}|eg\rangle + C_{22}|ee\rangle$$

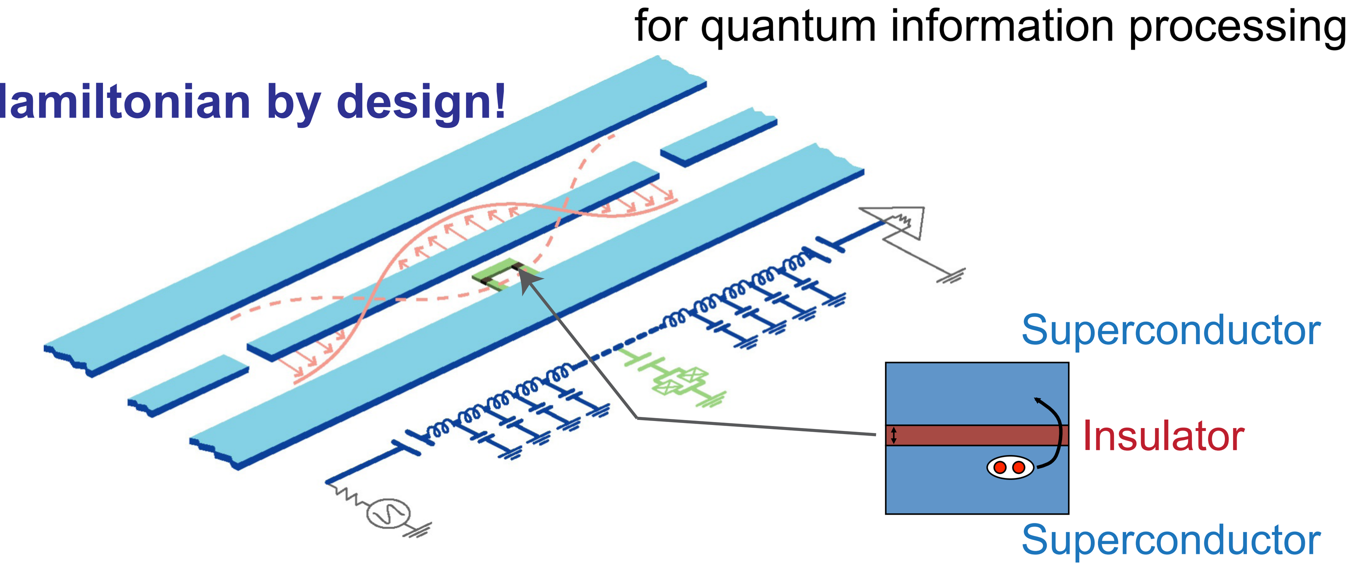
N qubits need 2^N coefficients

A 200-qubit register
= more classical bits than atoms in the universe!

Superconducting Quantum Circuits

One of the most promising experimental platforms for quantum information processing

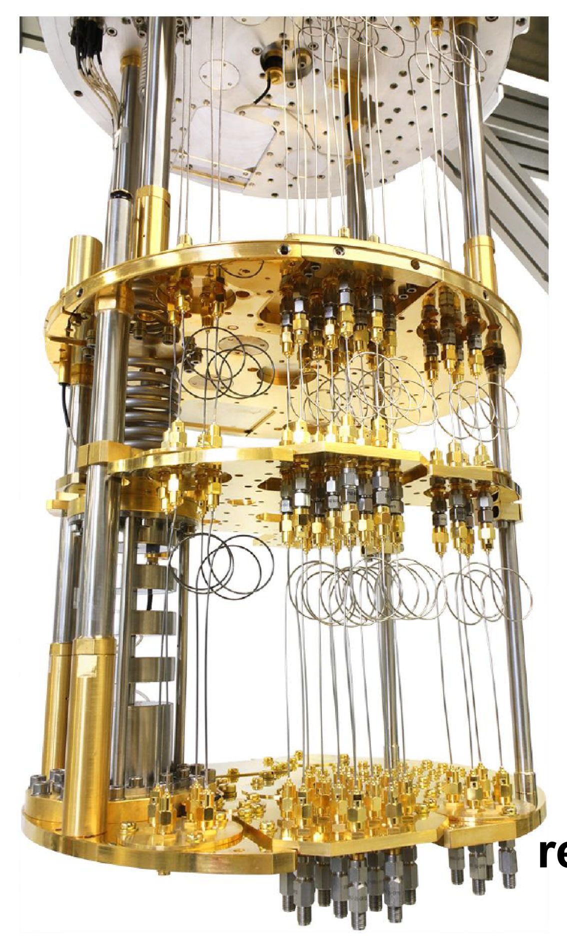
Hamiltonian by design!



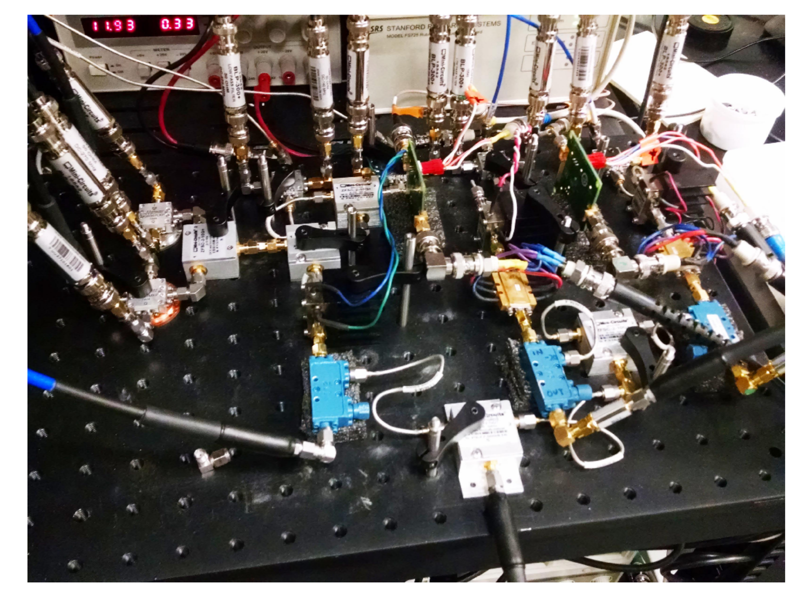
Superconducting LC resonators = quantum harmonic oscillator
Josephson junction circuits = artificial atoms (qubits)

Collective current/voltage excitations --> described by $|\psi\rangle$

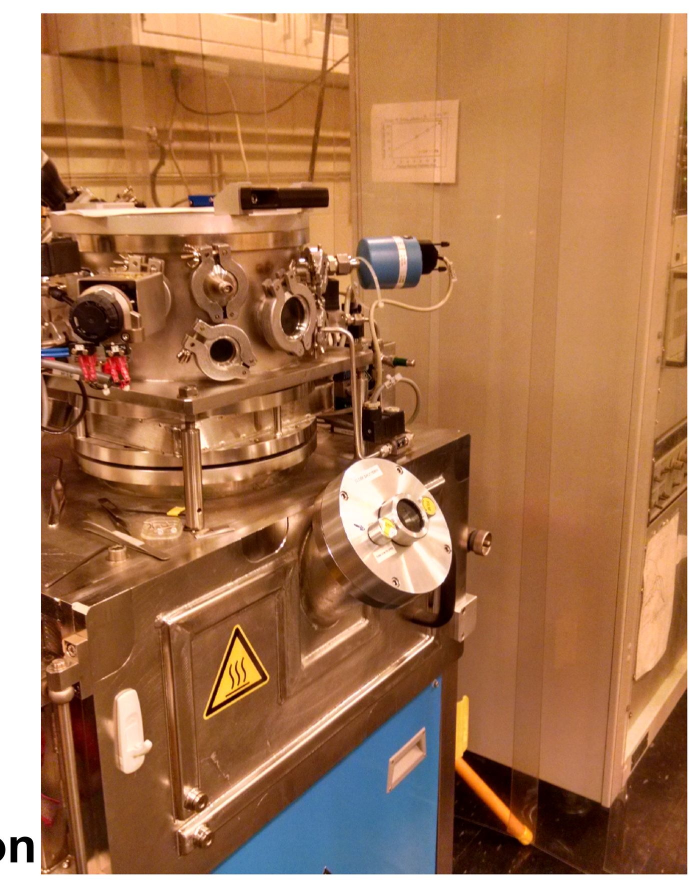
Equipment, Devices and Experimental methods



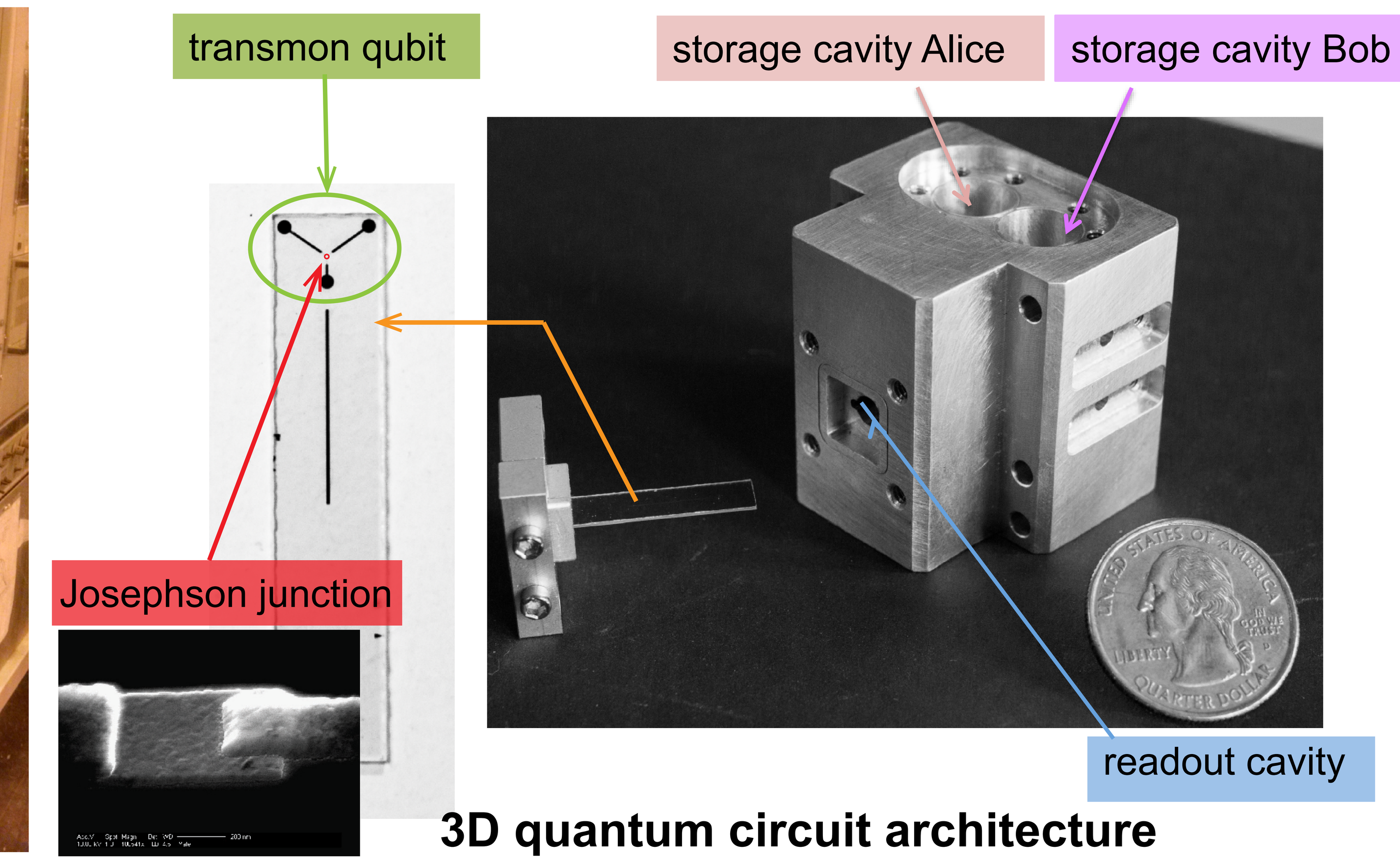
Dilution refrigerator



Microwave electronics



Evaporator for device fabrication



3D quantum circuit architecture

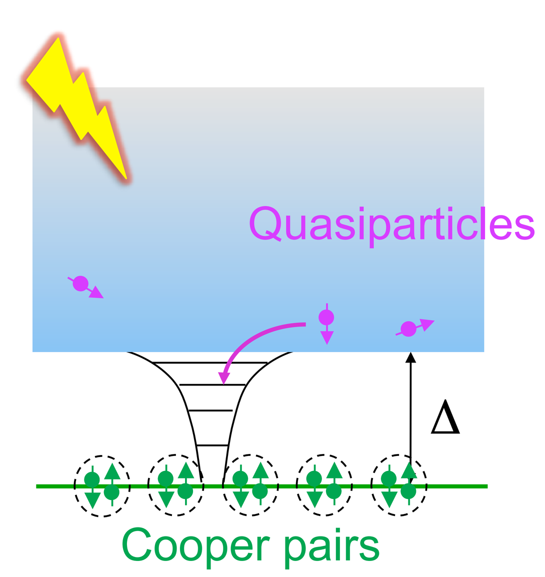
Study of Decoherence and Superconductivity

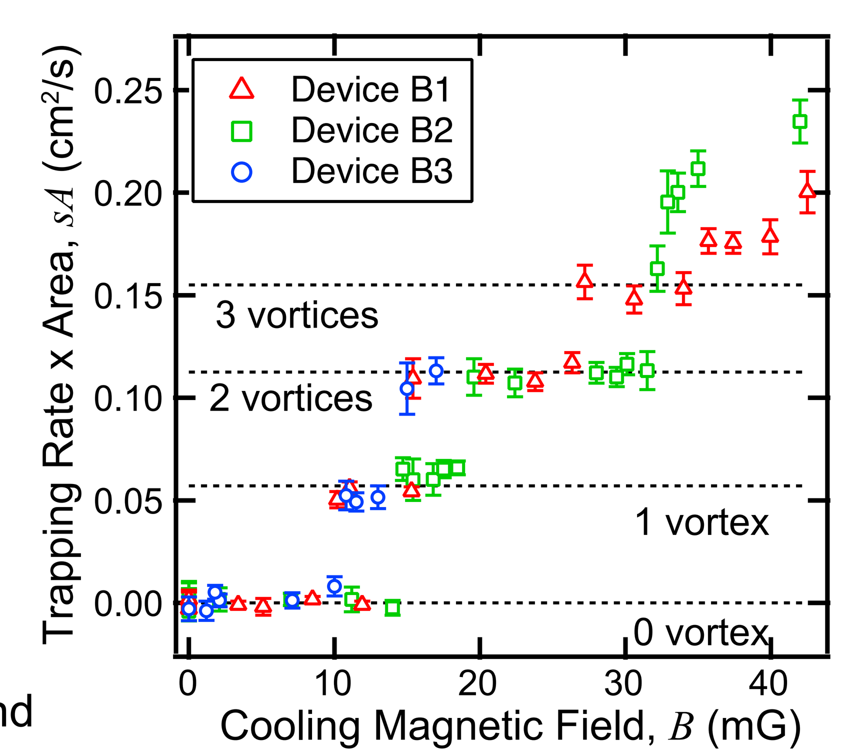
Does a quantum state in the lab live forever?
The environment is watching, and that is a problem!

Decoherence
- Energy relaxation --> T_1 time
- Dephasing --> T_ϕ time

We identify various unintend coupling between our qubits and external degrees of freedom to improve the coherence times. This is also often a rewarding process to learn more about our solid state system.

Example:
Non-equilibrium quasiparticle excitations in our superconducting qubits can cause qubit decay, but a few vortices can help remove them.



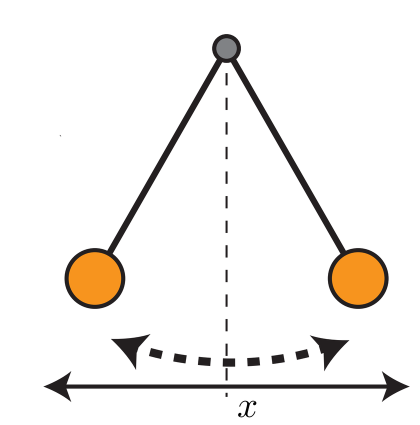


We measured the interaction between individual vortices and quasiparticles!

C. Wang, et al., Nature Communications 5, 5836 (2014)

Controlling Mesoscopic Entangled States

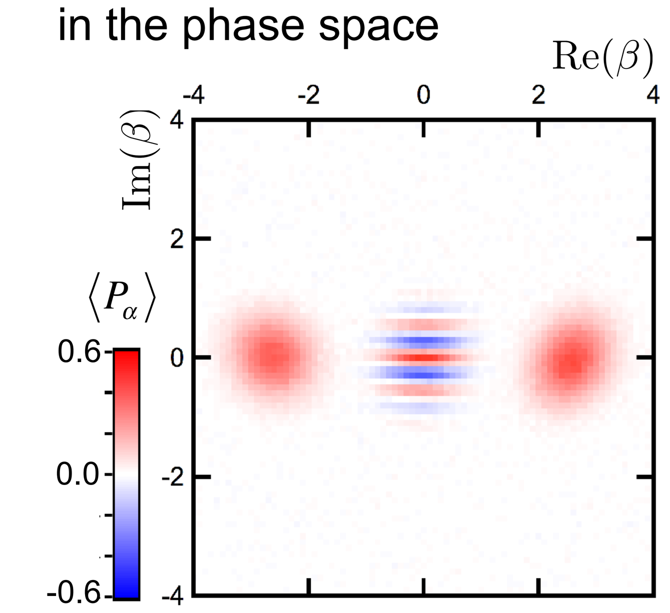
Heard of Schrodinger's cat?
Nowadays we can place objects a little more macroscopic than qubits into superposition or entangled states!



$$|\psi\rangle = \frac{1}{\sqrt{2}}|\text{cat alive}\rangle + \frac{1}{\sqrt{2}}|\text{cat dead}\rangle$$
$$\Downarrow$$
$$|\psi\rangle = \frac{1}{\sqrt{2}}|\alpha\rangle + \frac{1}{\sqrt{2}}|-\alpha\rangle$$

"Cat state" of a harmonic oscillator:
superposition of coherent states
(of microwave fields in our experiments)

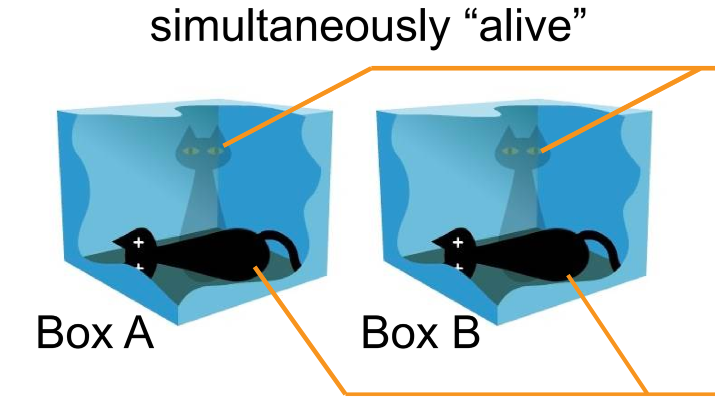
Wigner function representation in the phase space

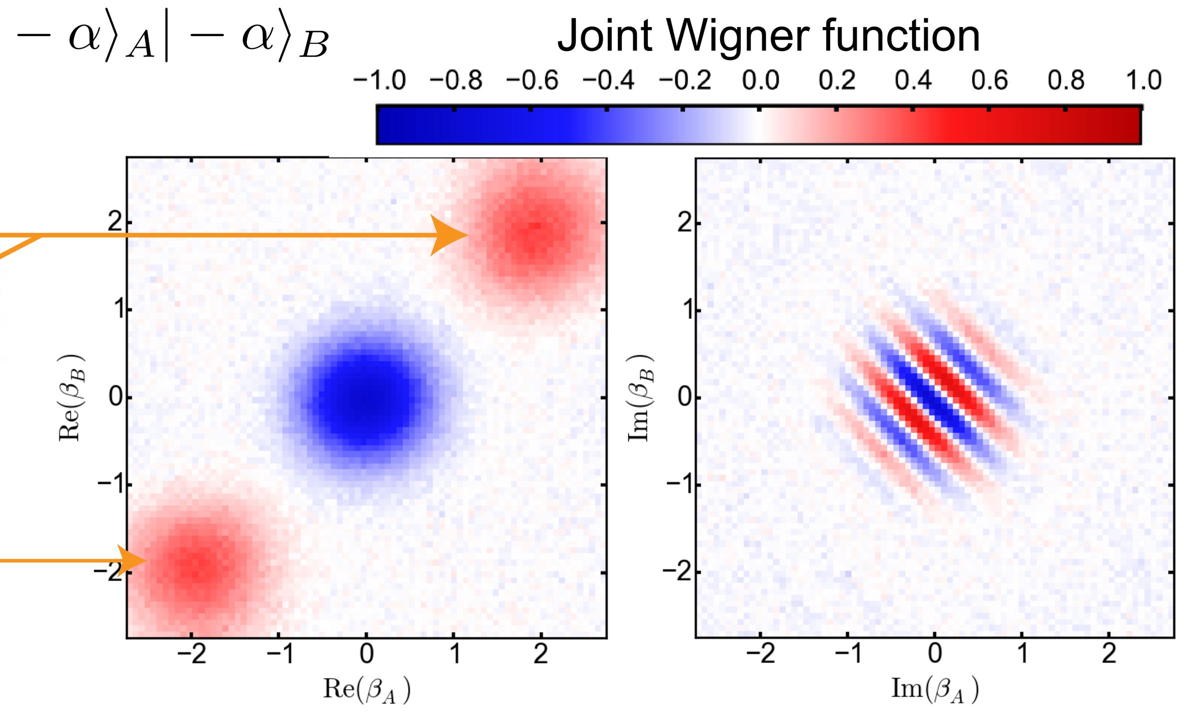


Two-mode cat state:

$$|\psi\rangle = \frac{1}{\sqrt{2}}|\alpha\rangle_A|\alpha\rangle_B + \frac{1}{\sqrt{2}}|-\alpha\rangle_A|-\alpha\rangle_B$$

Joint Wigner function





C. Wang, et al., arXiv: 1601.05505 (to appear in Science)