"I have good news and bad news"
PROTECTING QUANTUM SUPERPOSITIONS IN JOSEPHSON CIRCUITS

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Sponsors:

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PROTECTING QUANTUM SUPERPOSITIONS IN JOSEPHSON CIRCUITS

LECTURE I: INTRODUCTION AND OVERVIEW

LECTURE II: CAT CODES

LECTURE III: PARITY MONITORING AND CORRECTION
PROTECTING CLASSICAL INFORMATION

ONE BIT OF INFORMATION ENCODED IN A SWITCH

ENERGY BARRIER PROTECTS INFORMATION

\[ \Gamma_{\text{error}} \sim \exp \left( -\frac{\Delta U}{k_B T} \right) \]

\[ \Delta U \gg k_B T \]
ELEMENT OF QUANTUM INFORMATION: QUBIT

Two basis quantum states:

$|0\rangle$  $|1\rangle$

Generic superposition:

$|\Psi\rangle = \cos\frac{\theta}{2}|0\rangle + \exp i\phi \sin\frac{\theta}{2}|1\rangle$

MUST PRESERVE ALL SUPERPOSITIONS, I.E. THE ENTIRE SPHERE
CARDINAL POINTS OF THE BLOCH SPHERE

$|Z = +1\rangle$
$|Z = -1\rangle$
$|X = +1\rangle$
$|X = -1\rangle$
$|Y = +1\rangle$
$|Y = -1\rangle$
DECOHERENCE: LOSS OF INFORMATION

"T₁"  "Tₚ"
BY CAREFUL ENCODING IN A LARGE ENOUGH SPACE, QUANTUM INFORMATION CAN BE PROTECTED

SIMPLE EXAMPLE:

\[ |\Psi\rangle = \cos \frac{\theta}{2} |\uparrow \downarrow\rangle + e^{i\phi} \sin \frac{\theta}{2} |\downarrow \uparrow\rangle \]

X AND Y COMPONENTS IN \( M = 0 \) MANIFOLD ARE PROTECTED FROM NOISE IN COMMON MODE MAGNETIC FIELD \( B \)

IN GENERAL:

ELEMENTARY ERRORS \( E \) ONLY MOVE OCTAHEDRON ALONG A 3+n\(^{th}\) DIMENSION, WITHOUT CHANGING ITS VOLUME
3 STRATEGIES FOR PROTECTING QUANTUM INFORMATION

- Encode using defects in topological quantum matter
  Example: Majorana fermions

- Encode into a register of qubits, monitor multi-qubit parities
  Examples: Steane & surface codes

- Encode into a quantum cavity resonator and monitor photon number parity
  Example: cat codes
REGISTER ERROR CORRECTION: STEANE CODE

\[
|0_L\rangle = \begin{pmatrix}
|0\rangle & |0\rangle & |0\rangle & |0\rangle \\
|0\rangle & |1\rangle & |0\rangle & |1\rangle \\
|0\rangle & |1\rangle & |1\rangle & |1\rangle \\
|1\rangle & |0\rangle & |1\rangle & |1\rangle \\
\end{pmatrix}
\]

\[
|1_L\rangle = \begin{pmatrix}
|1\rangle & |1\rangle & |0\rangle & |0\rangle \\
|1\rangle & |0\rangle & |1\rangle & |0\rangle \\
|1\rangle & |0\rangle & |1\rangle & |0\rangle \\
|0\rangle & |1\rangle & |0\rangle & |0\rangle \\
\end{pmatrix}
\]
STEANE CODE ERROR CORRECTION PROTOCOL

\[ i = 0 \]

\[
\begin{array}{cccccc}
Z & Z & Z & X & X & X \\
Z & Z & X & X & X & X \\
Z & Z & X & X & X & X \\
Z & Z & X & X & X & X \\
Z & Z & X & X & X & X \\
Z & Z & X & X & X & X \\
j = 0 & e_j & j = 5
\end{array}
\]

\[ i = 6 \]

\[
\begin{array}{cccccc}
Z & Z & Z & X & X & X \\
Z & Z & X & X & X & X \\
Z & Z & X & X & X & X \\
Z & Z & X & X & X & X \\
Z & Z & X & X & X & X \\
Z & Z & X & X & X & X \\
j = 0 & e_j & j = 5
\end{array}
\]
SUPERCONDUCTING QUBIT PARADIGM: CONSIDER A SINGLE, DRIVEN ELECTROMAGNETIC MODE...
ATOM vs CIRCUIT

Hydrogen atom

Superconducting LC oscillator

- metallic lattice
- positive ions
- electron condensate

$L$ $C$
ATOM vs CIRCUIT

Hydrogen atom

Superconducting LC oscillator

$L \quad C$

electron condensate

metallic lattice
positive ions
ATOM vs CIRCUIT

Hydrogen atom

Superconducting LC oscillator

unique electron → whole superconducting condensate
velocity of electron → current through inductor
force on electron → voltage across capacitor
ATOM vs CIRCUIT

Hydrogen atom

Superconducting LC oscillator

unique electron $\rightarrow$ whole superconducting condensate
velocity of electron $\rightarrow$ current through inductor
force on electron $\rightarrow$ voltage across capacitor
LC CIRCUIT AS A QUANTUM HARMONIC OSCILLATOR

\[ \hat{\Phi} = LI, \quad Q = CV \]

\[ [\hat{\Phi}, \hat{Q}] = i\hbar \]

Diagram showing the energy levels and the Hamiltonian of the LC circuit as a quantum harmonic oscillator.
In every energy eigenstate, (microwave photon state) current flows in opposite directions simultaneously!
EFFECT OF DAMPING

important: as little resistance as possible

dissipation broadens energy levels

\[
E_n = \hbar \omega_r \left[ n \left( 1 + \frac{i}{2Q} \right) + \frac{1}{2} \right]
\]

\[
Q = RC\omega_r
\]
CAN PLACE CIRCUIT IN ITS GROUND STATE

some cold dissipation is actually needed: provides reset of circuit!

\[ \hbar \omega_r \gg k_B T \]

10-5 GHz \quad 10mK
UNLIKE ATOMS IN VACUUM, TWO CIRCUITS EASILY COUPLE THROUGH THEIR WIRES:

COUPLING CAN BE ARBITRARILY STRONG! HAMILTONIAN BY DESIGN!
CAVEAT: THE QUANTUM STATES OF A PURELY LINEAR CIRCUIT CANNOT BE FULLY CONTROLLED!

NO STEERING TO AN ARBITRARY STATE IF SYSTEM PERFECTLY LINEAR.
NEED NON-LINEARITY TO FULLY REVEAL QUANTUM MECHANICS
Potential energy

Emission spectrum @ high T

Frequency

\[ \omega_{34}, \omega_{23}, \omega_{12}, \omega_{01} \]
NEED NON-LINEARITY TO FULLY REVEAL QUANTUM MECHANICS

Potential energy

Position coordinate

Emission spectrum

|0⟩ | |1⟩ | |2⟩ | |3⟩ | |4⟩

absolute non-linearity is ratio of peak distance to peak width

ω_{01} ω_{12} ω_{23} ω_{34}
JOSEPHSON TUNNEL JUNCTION: A NON-LINEAR INDUCTOR WITH NO DISSIPATION

1nm

S
I
S

100 - 1000 nm

superconductor-insulator-superconductor tunnel junction

MIGHT BE SUPERSEDED SOME DAY BY ANOTHER DEVICE (BASED ON ATOMIC POINT CONTACTS, NANOWIRES, ???)
JOSEPHSON TUNNEL JUNCTION: A NON-LINEAR INDUCTOR WITH NO DISSIPATION

\[ I = \phi / L_J \]

\[ \phi = \int_{-\infty}^{t} V(t') \, dt' \]

\[ I = I_0 \sin(\phi / \phi_0) \]

\[ \phi_0 = \frac{\hbar}{2e} \]
PROTECTING QUANTUM SUPERPOSITIONS IN JOSEPHSON CIRCUITS

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JOSEPHSON TUNNEL JUNCTION: A NON-LINEAR INDUCTOR WITH NO DISSIPATION

\[ U = -E_J \cos \left( \frac{\phi}{\phi_0} \right) \]

bare Josephson potential

\[ \phi_0 = \frac{\hbar}{2e} \]

\[ L_J = \frac{\phi_0^2}{E_J} \]
ELECTROMAGNETIC OSCILLATOR ENDOWED WITH JOSEPHSON NON-LINEARITY

Potential energy

Position coordinate

Emission spectrum @ high T

Kerr frequency

\[ \omega_{34} \quad \omega_{23} \quad \omega_{12} \quad \omega_{01} \]
QUANTUM STATES OF A HARMONIC OSCILLATOR

REPRESENTED BY THEIR QUASI-PROBABILITY WIGNER FUNCTION IN PHASE SPACE

\[ W(\beta) = \langle D_\beta PD_\beta \rangle; P = (-1)^{a^\dagger a} \]

\[ \beta = I + iQ \]

vacuum: \( |n=0> \)

1 photon: \( |n=1> \)

coherent state: \( |\alpha = 2> \)

squeezed vacuum

cat state

\( |\alpha> + |\alpha> \) / \( \sqrt{2} \)
QUANTUM STATES OF A HARMONIC OSCILLATOR

REPRESENTED BY THEIR QUASI-PROBABILITY WIGNER FUNCTION IN PHASE SPACE

\[ W(\beta) = \langle D_{-\beta} PD_{\beta} \rangle; P = (-1)^{a^+a} \]

\[ \beta = I + iQ \]

vacuum: \( |n=0> \)

1 photon: \( |n=1> \)

coherent state

squeezed vacuum

cat state

\[ |\alpha = 2> \]

\[ \frac{|\alpha> - |-\alpha>}{\sqrt{2}} \]
\[ |0\rangle_L = \mathcal{N}(|\alpha\rangle + |\alpha\rangle) \]

\[ |1\rangle_L = \mathcal{N}(|i\alpha\rangle + |-i\alpha\rangle) \]

\[ |\alpha = 3\rangle \]

\[ \mathcal{N}(|\alpha\rangle) \]

typical

\[ \Delta t = \kappa^{-1} \]

\[ \hat{a} |\alpha\rangle = \alpha |\alpha\rangle \]

\[ i\mathcal{N}(|i\alpha\rangle) \]

odd
BLOCH SPHERE OF 4-LEG CAT CODE

Leghtas et al. PRL (2013)
Mirrahimi et al. NJP (2014)
TWO TYPES OF CAT ERROR MUST BE ADDRESS:

- COHERENT STATE SHRINKING, DEPHASING & DEFORMING

- PHOTON NUMBER PARITY JUMPING

HOW DO WE FULLY CONTROL THE RESONATOR?
DEVICES

3.4 cm

0.5 mm

1.2 cm

H. Paik et al. PRL (2011)
EXPERIMENTAL SETUP

- 77 K
- 4 K
- 1 K
- 100 mK
- 20 mK
- quantum circuits
- dilution refrigerator

- microwave generators
- arbitrary waveform generator
- atomic clock
- amplifier electronics
- acquisition card
- instrument rack

Instrument rack

0.5 m
2 OSCILLATORS COUPLED THROUGH A TUNNEL JOSEPHSON JUNCTION

SIMPLIFIED MODEL

\[
H = \frac{Q_s^2}{2C_s} + \frac{\Phi_s^2}{2L_s} + \frac{Q_r^2}{2C_r} + \frac{\Phi_r^2}{2L_s} - E_J \cos \left[ \frac{(\Phi_r - \Phi_s)}{\phi_0} \right]
\]

\[
\omega_{r,s}^0 = \sqrt{L_{r,s}C_{r,s}}
\]
A powerful deterministic gate combining microwave light and a qubit

\[ H = \chi a^{\dagger} a \sigma_z \]

\[ \omega_c - \omega_q \gg \chi \gg \kappa \gg T_2^{-1} \]

strong dispersive regime: Stark shift per photon > 1000 linewidths

Can combine two cavities, a qubit and a quantum limited Josephson amplifier:

2 OSCILLATORS COUPLED THROUGH A TUNNEL JOSEPHSON JUNCTION

TE101 modes

storage

junction

dump & readout

storage

junction

dump & readout

$\vec{E}$

$\omega_s$

$\omega_q$

$\omega_r$
2 OSCILLATORS COUPLED THROUGH A TUNNEL JOSEPHSON JUNCTION

\[ H / \hbar = \omega_s a_s^\dagger a_s + \omega_r a_r^\dagger a_r + \omega_q a_q^\dagger a_q + \frac{qq}{2} (a_q^\dagger)^2 (a_q)^2 q_s a_q^\dagger a_q s_q a_s^\dagger a_s q_r a_q^\dagger a_q r_q a_r^\dagger a_r + \ldots \]

\[ \frac{rs}{4} (a_s)^2 (a_r^\dagger)^2 + \text{h.c.} + \ldots \]
NON-DEMOLITION MEASUREMENT OF SUPERCONDUCTING ATOM

Readout amplitude
\[ \sqrt{I^2 + Q^2} \]

Readout phase
\[ \tan^{-1}\left(\frac{Q}{I}\right) \]

\[ \text{Cavity QED: Pioneering expts in Haroche's and Kimble's groups} \]

\[ \text{Circuit QED: Wallraff et al. (2004), Houck et al., (2007), Gambetta et al. (2008), Vijay et al., (2012).} \]

\[ \text{Josephson pre-amp} \]

\[ \text{HEMT-amp} \]

\[ \text{Q} \]

\[ \text{ref} \]

\[ I \]

\[ \text{JPC} \]

\[ \text{f} \]

\[ f_c \]

\[ \chi \]

\[ \kappa \sim \chi \]

\[ \theta \sim \pi/2 \]
QUANTUM JUMPS OF QUBIT STATE

~90% of fluctuations of signal at 300K are quantum noise!

~2000 bits per qubit lifetime
TWO TYPES OF CAT ERRORS MUST BE ADDRESSED:

- COHERENT STATE SHRINKING, DEPHASING & DEFORMING

- PHOTON NUMBER PARITY JUMPING
REVIEW THE USUAL DRIVEN-DAMPED HARMONIC OSCILLATOR
REVIEW THE USUAL DRIVEN-DAMPED HARMONIC OSCILLATOR
REVIEW THE USUAL DRIVEN-DAMPED HARMONIC OSCILLATOR
REVIEW THE USUAL DRIVEN-DAMPED HARMONIC OSCILLATOR
Hamiltonian: \[ H = e_1^* a + e_1^\dagger a \]

loss operator: \[ \sqrt{a} = 2i_1 / 1 \]
AVERAGE EVOLUTION OF DENSITY MATRIX FOR AN OPEN SYSTEM

\[
\frac{d}{dt} \rho = -i[H, \rho] + \mathcal{D} [c] \rho
\]

\[
\mathcal{D} [c] \rho = c \rho c^\dagger - \frac{1}{2} \left( c^\dagger c \rho + \rho c^\dagger c \right)
\]

loss operator
A SPECIAL DRIVEN-DAMPED OSCILLATOR
A SPECIAL DRIVEN-DAMPED OSCILLATOR

Force $\sim X^2$
A SPECIAL DRIVEN-DAMPED OSCILLATOR

Force \sim X^2

Damping \sim V^2
A SPECIAL DRIVEN-DAMPED OSCILLATOR

Re(β)  Im(β)

Wigner function $W(\beta)$
A SPECIAL DRIVEN-DAMPED OSCILLATOR

\[
H = e^{2}a^{2} + e(a^{\dagger})^{2}
\]

Hamiltonian:

\[
H = e^{2}a^{2} + (a^{\dagger})^{2}
\]

Loss operator:

\[
\sqrt{2}a^{2} = \pm \sqrt{2i/2}
\]

Wigner function \( W(\beta) \)
A SPECIAL DRIVEN-DAMPED OSCILLATOR

Hamiltonian: \( H = 2^*a^2 + (a^\dagger)^2 \)

loss operator: \( \sqrt{2}a^2 = \pm \sqrt{2i} \frac{l}{2} \)

2 OSCILLATORS COUPLED THROUGH A TUNNEL JOSEPHSON JUNCTION

TE101 modes
2 OSCILLATORS COUPLED THROUGH A TUNNEL JOSEPHSON JUNCTION

\[
H / \hbar = \omega_s a_s^\dagger a_s + \omega_r a_r^\dagger a_r + \omega_q a_q^\dagger a_q + \frac{qq}{2} (a_q^\dagger)^2 (a_q)^2 + \frac{qs}{q_s} a_q^\dagger a_q a_s^\dagger a_s + \frac{qr}{q_r} a_q^\dagger a_q a_r^\dagger a_r + \ldots
\]

basis

\[
\frac{rs}{4} (a_s)^2 (a_r^\dagger)^2 + \text{h.c.} + \ldots
\]
TWO-PHOTON EXCHANGE BETWEEN THE 2 CAVITIES

density of states

\( \omega_p = 2\omega_s - \omega_d \)

effective drive Hamiltonian: \( \frac{1}{2}(a_s^\dagger)^2 + \text{h.c.} \)

effective loss operator: \( \sqrt{2}a_s^2 \)

\[ H_{sr} = g^2 a_s^2 a_r^\dagger + \text{h.c.} \]
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)

\[ \text{Re}(\beta) = I \]

\[ \text{Im}(\beta) = Q \]
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)

\[ \pi/2 \ W(\beta) \]

\[ \text{Re}(\beta) \]

\[ \text{Im}(\beta) \]
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)

$\pi/2 \ W(\beta)$
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)

$\pi/2 W(\beta)$

$\text{Re}(\beta)$

$\text{Im}(\beta)$

$3\pi/4$

$\pi/2$

$\pi/4$

$\pi$

$-3\pi/4$

$0$
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)
CAVITY BI-STABLE BEHAVIOR (SEMI-CLASSICAL)

see also Puri and Blais arXiv:1605.09408
CAT SQUEEZES OUT OF VACUUM!

pumping time: 0 μs, 2 μs, 7 μs, 19 μs

raw data

reconstruction

numerical simulation

quantum interference!
CAT SQUEEZES OUT OF VACUUM!

Data of two years ago... \( \frac{\kappa_2}{\kappa_1} \approx 1 \) with \( 1/\kappa_1 = 20 \mu s \)

- Pumping time
  - 0 μs
  - 2 μs
  - 7 μs
  - 19 μs

- Raw data
- Reconstruction
- Numerical simulation

\( W(\beta) \)

Quantum interference!

Leghtas et. al. Science (2015)
NOW: \( \frac{\kappa_2}{\kappa_1} = 100 \) with \( 1/\kappa_1 = 92 \mu s \)

M. Reagor et al., APL (2013),
C. Axline et al. APL (2016)

Wigner qubit separate from storage ancilla

NOW:

\[
\frac{\kappa_2}{\kappa_1} = 100 \text{ with } 1/\kappa_1 = 92 \text{ } \mu\text{s}
\]

Wigner qubit separate from storage ancilla

M. Reagor et al., APL (2013), C. Axline et al. APL (2016)

RABI OSCILLATIONS OF CAT WHILE PUMPING

\[ |0\rangle_L = \frac{|\alpha \rangle + |-\alpha \rangle}{\sqrt{2}} \]

\[ |1\rangle_L = \frac{|\alpha \rangle - |-\alpha \rangle}{\sqrt{2}} \]

observation of quantum Zeno dynamics of protected information!

Misra & Sudarshan (1977); Itano et al., (1990); Fisher, Gutierrez-Medina & Raizen (2001); Facchi & Pascazio (2002); Raimond et al., (2012)
MEASUREMENT OF THE 4 PAULI OPERATORS OF THE PROTECTED QUBIT MANIFOLD

\[ I = X_1^1 + X_2^2 \]

\[ X = X_2^2 - X_1^1 \]
PROCESS TOMOGRAPHY OF QUANTUM ZENO RABI ROTATION

Encode

\[ \begin{align*}
\text{ Encode:} & \quad \text{N}(|\alpha\rangle \pm |\alpha\rangle) \\
\text{ or } & \quad \text{N}(|\alpha\rangle \pm i|\alpha\rangle) \\
\text{ or } & \quad |\pm \alpha\rangle
\end{align*} \]
Identity

+X

+Y

+Z
Zeno $\pi/2$ rotation around X

DURATION OF LOGICAL GATES: 1.8 $\mu$s

GATE DONE WHILE CORRECTING!
TWO TYPES OF CAT ERRORS MUST BE ADDRESSED:

- COHERENT STATE SHRINKING, DEPHASING & DEFORMING

- PHOTON NUMBER PARITY JUMPING
SYNDROME MEASUREMENT

cavity

\[ t = \frac{\pi}{X_{sa}} X_{\frac{\pi}{2}} \]

transmon

\[ \begin{align*}
  X_{\frac{\pi}{2}} & \\
  X_{sa} & \\
  X_{\frac{\pi}{2}} & \\
\end{align*} \]

\[ \cdots \]

transmon

cavity

\[ \text{Re}(\beta) \]

\[ \text{Im}(\beta) \]
SYNDROME MEASUREMENT

cavity

\[
t = \frac{\pi}{X_{sa}}
\]

cavity

transmon

\[
X_{\frac{\pi}{2}}
\]

cavity

Re(\beta)

Im(\beta)

transmon
SYNDROME MEASUREMENT

\[ |n = \text{even}\rangle \]
\[ |n = \text{odd}\rangle \]

\[ t = \frac{\pi}{\chi_{sa}} \]

\[ \theta = \chi_{sa} t \]

\[ \text{transmon} \] \hspace{1cm} \text{cavity} \]
SYNDROME MEASUREMENT

\[ n = \text{even} \]
\[ n = \text{odd} \]

\[ t = \frac{\pi}{X_{sa}} \]

transmon cavity

<table>
<thead>
<tr>
<th>[ n = \text{even} ]</th>
<th>[ n = \text{odd} ]</th>
</tr>
</thead>
</table>

\[ \text{Re}(\beta) \]
\[ \text{Im}(\beta) \]
SYNDROME MEASUREMENT

\[ t = \frac{\pi}{X_{sa}} \]

\[ X_{=\pi/2} \]

\[ X_{=\pi/2} \]

\[ |n = \text{even}\rangle \]

\[ |n = \text{odd}\rangle \]

\[ \text{Re}(\beta) \]

\[ \text{Im}(\beta) \]
SYNDROME MEASUREMENT

\[ t = \frac{\pi}{\chi_{sa}} \quad X_{\frac{\pi}{2}} \quad X_{-\frac{\pi}{2}} \]

\[ |n = \text{even}\rangle \]

transmon

cavity

\[ \text{Im}(\beta) \]

\[ \text{Re}(\beta) \]
REAL-TIME QUANTUM CONTROLLER FOR FEEDFORWARD CORRECTION

- Commercial FPGA with custom software developed at Yale
- Single system performs all measurement, control, & feedback (latency~200ns)
- Real-time decision making and on-the-fly pulse generation → essentially infinite program/sequence length
4-CAT ENCODING SLOWS DOWN QUANTUM INFORMATION DECAY

Qubit after 109 $\mu$s

Fidelity = 0.26

Fidelity = 0.58

Fidelity = 0.72

QEC = Quantum Error Correction from Parity Monitoring using Field Programmable Gate Array

Ofek & Petrenko et al., Nature (2016)
MULTI-CAVITY ARCHITECTURES

The “Y-mon”!!

other experiments currently underway in the lab with 5 to 10 qubits and 5 to 10 cavities

M. Reagor et al., APL (2013), C. Axline et al. (in preparation)
JOINT WIGNER FUNCTION OF THE TWO-MODE CAT

\[ W_J(a_A, a_B): \text{ a function in a 4D space} \]

\[ | \gamma = a_A a_B - (-a_A - a_B) \]

(\(\gamma = 1.92\))

Quantum coherence

Predicted Wigner for ideal state:

States live in Hilbert space of dimension \(\sim 150!\)

Ideal:


Measured:

SUMMARY AND PERSPECTIVES

• Quantum information protection can be static and/or dynamic

• Cat code encodes information in dynamical states: hardware efficiency

• Demonstration of operation while protecting

• Attained break-even point in quantum error correction

• Entanglement of two logical qubits

• Combine protection of cat energy loss and parity monitoring

• Demonstrate hierarchical layers of quantum error correction
MEET THE TEAM!

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