Quantum Simulation of arbitrary Hamiltonians with superconducting qubits

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Outline

- Quantum Simulation
- Superconducting simulator
  Quantum statics: Hamiltonian mapping
  Quantum dynamics
- Application to-i. Random real Hamiltonian
  ii. Molecular collisions

Introduction

- Definition: Quantum simulation is a process in which a quantum computer simulates another quantum system(Lloyd, ‘96).

- Corollary: A classical computer can also simulate quantum systems .

Superconducting simulator(1)

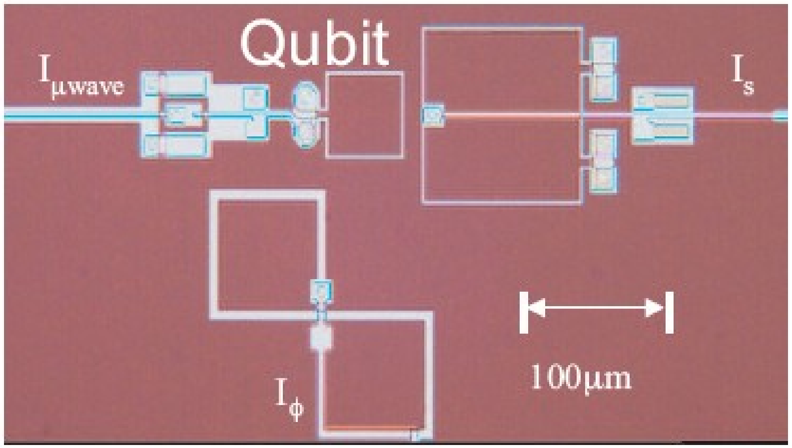
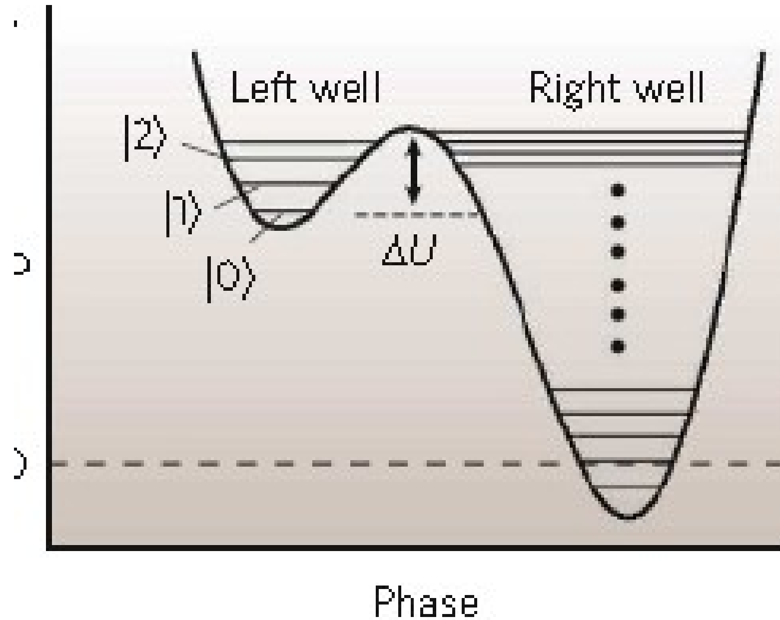


Figure 4: Single superconducting qubit device with associated microwave control and readout circuitry.



Superconducting simulator(2)

Hamiltonian

$$H_{qc} = \sum_i \begin{pmatrix} 0 & 0 \\ 0 & \bar{\epsilon} \end{pmatrix}_i + \sum_i \begin{pmatrix} 0 & 0 \\ 0 & \delta\epsilon_i(t) \end{pmatrix}_i + \sum_{ij} g_{ij}(t)\Phi_i\Phi_j,$$

$$\text{with } \Phi_i = (a\mathbf{I} + b\sigma^{\mathbf{z}} + c\sigma^{\mathbf{x}})_i,$$

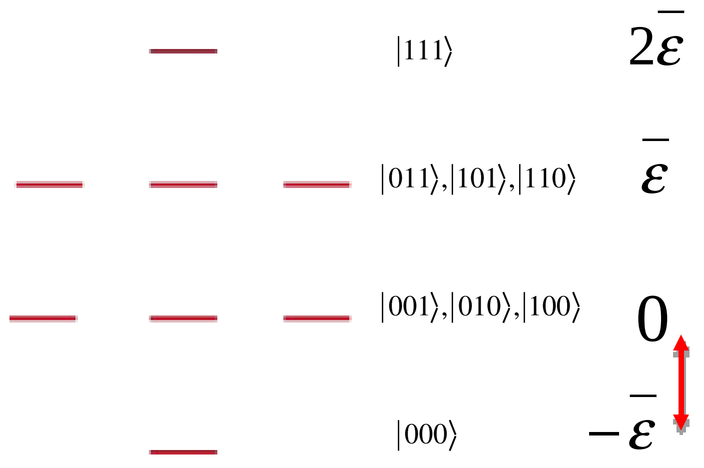
Rescaled energies

$$H_{qc} = \sum_i \begin{pmatrix} 0 & 0 \\ 0 & \delta\epsilon_i(t) \end{pmatrix}_i + \sum_{ij} g_{ij}(t)\Phi_i\Phi_j.$$

Superconducting simulator(3)

The 1-excitation subspace

$$n = 3 \quad \{|000\rangle, |001\rangle, |010\rangle, |011\rangle, |100\rangle, |101\rangle, |110\rangle, |111\rangle\}$$

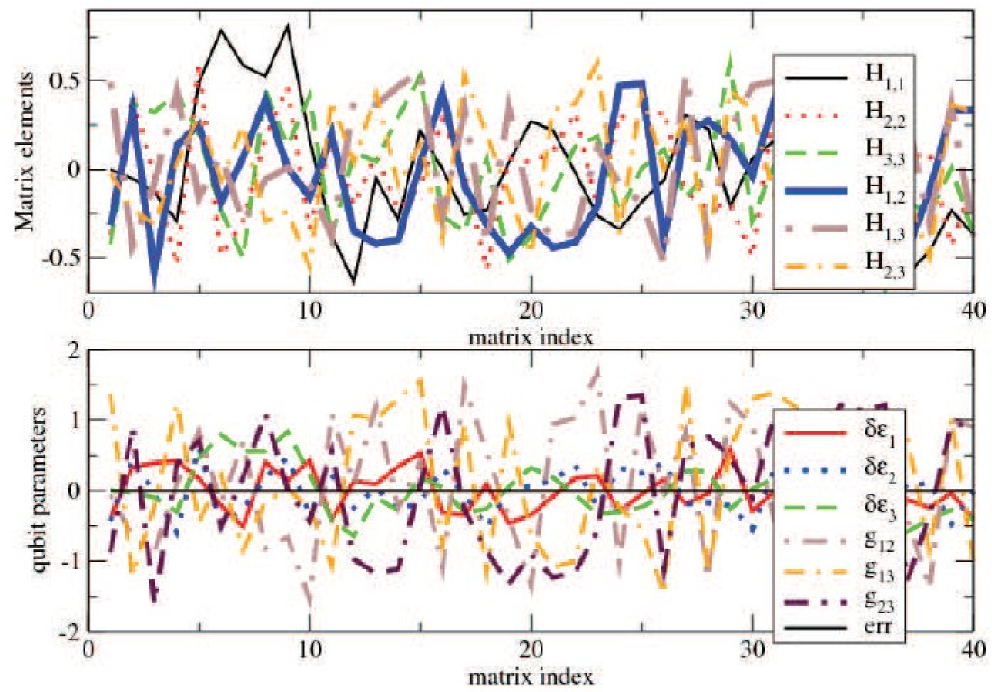


$$H_{qc} = \begin{pmatrix} \delta\varepsilon + f1 & g_{23} & g_{12} \\ & \delta\varepsilon + f2 & g_{13} \\ & & \delta\varepsilon + f3 \end{pmatrix}$$

f's are function of g's

Mapping(1)

- Random Hamiltonia



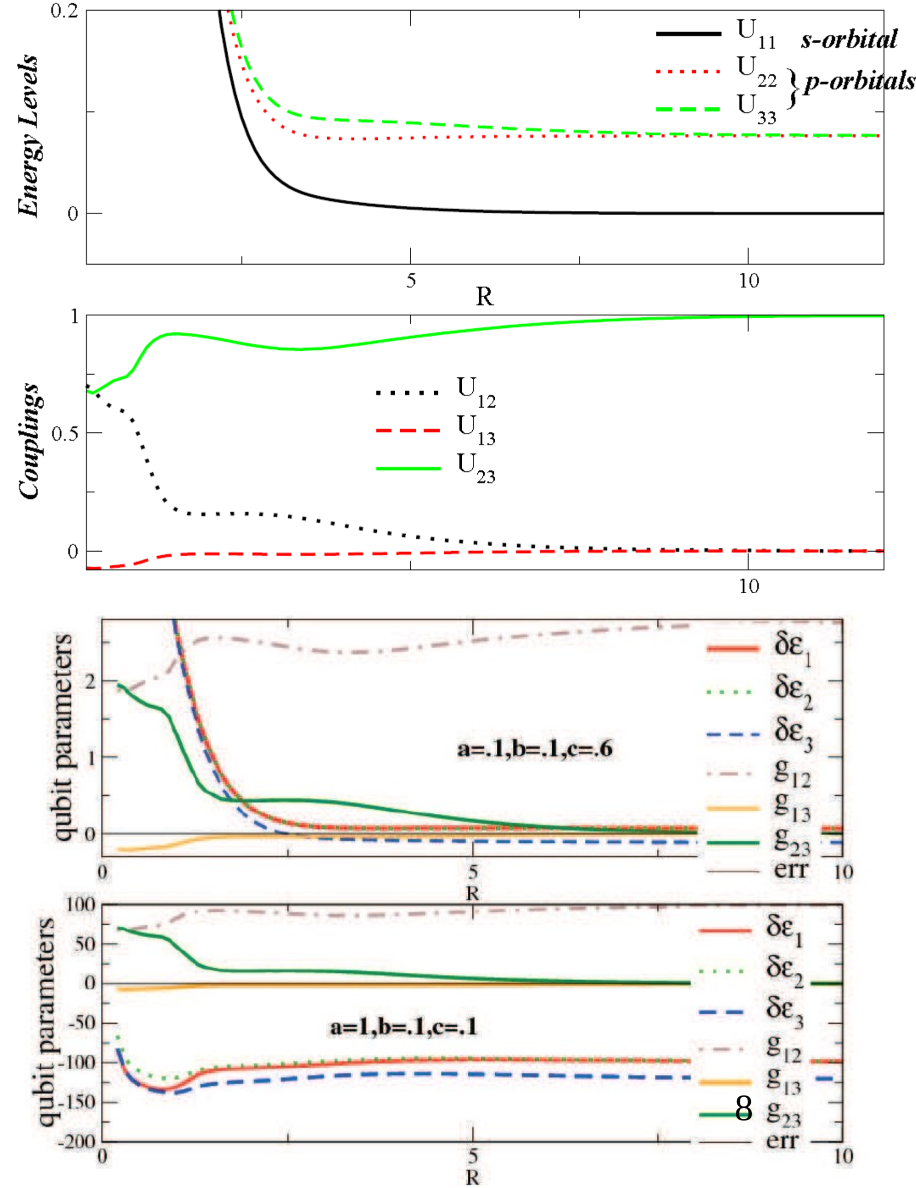
- Exact mapping:

err=$||H_{rand}-H_{qc}||=0$

Mapping (2)

- Molecular collision
- Na(3s)+He→Na(3p)+He
- err=$||H'/\lambda - H_{qc}||=0$

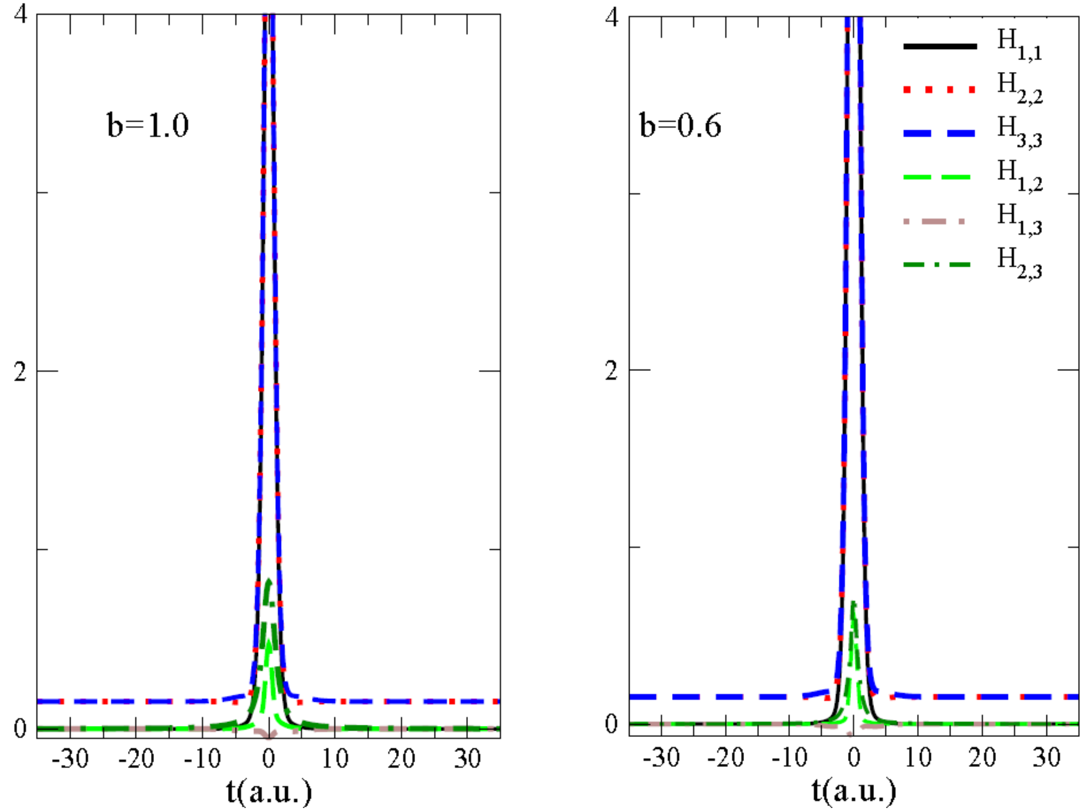
$\lambda = || H'(t) || / [\bullet 0.1\text{GHz}]$



Quantum dynamics: Molecular Collision(1)

Time dependent Hamiltonian

distance to
time transformation
$R^2 = b^2 + v^2 t^2$, $v=1$



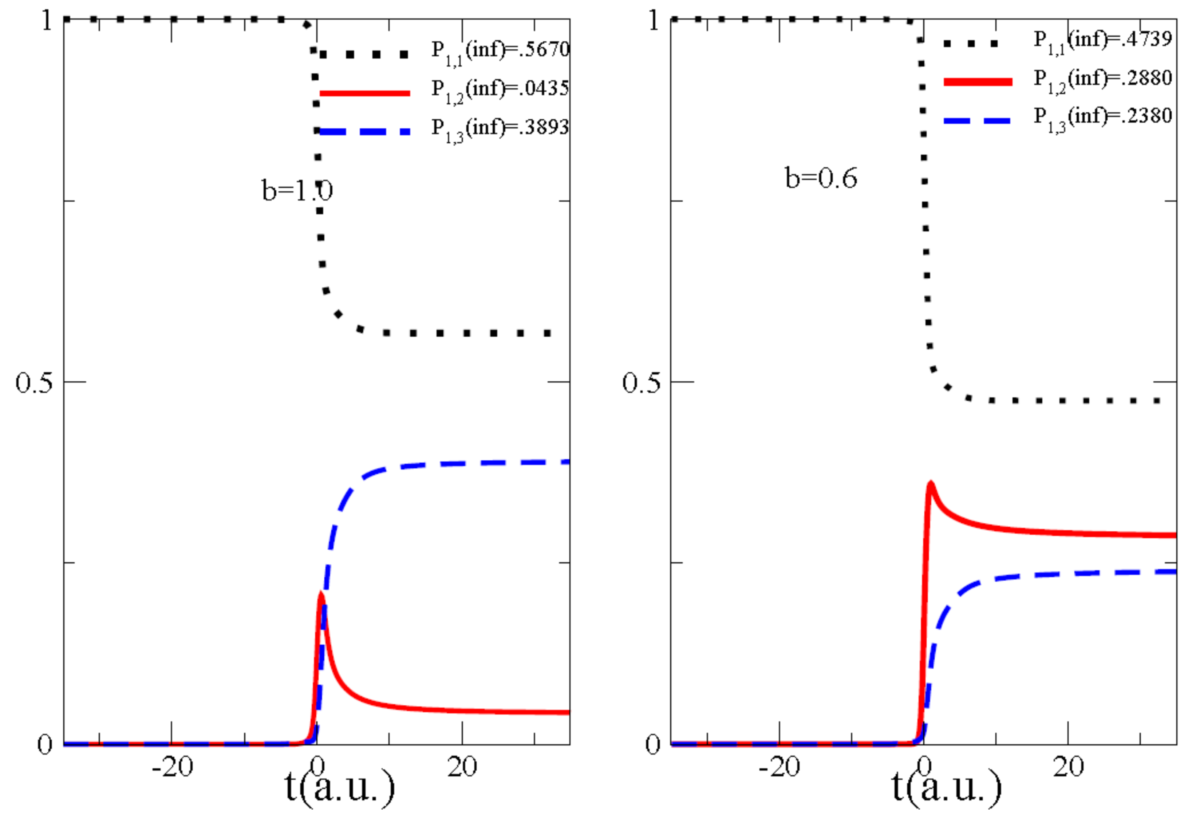
Quantum dynamics: Molecular Collision(2)

Scattering Probabilities

$$i\frac{d\mathbf{a}(t)}{dt} = H'(t)\mathbf{a}(t)$$

$$a_i(t \rightarrow -\infty) = \delta_{ij}$$

$$P_{ij} = |a_j(\infty)|^2$$



Quantum dynamics: Quantum Computer(1)

Energy-time rescaling

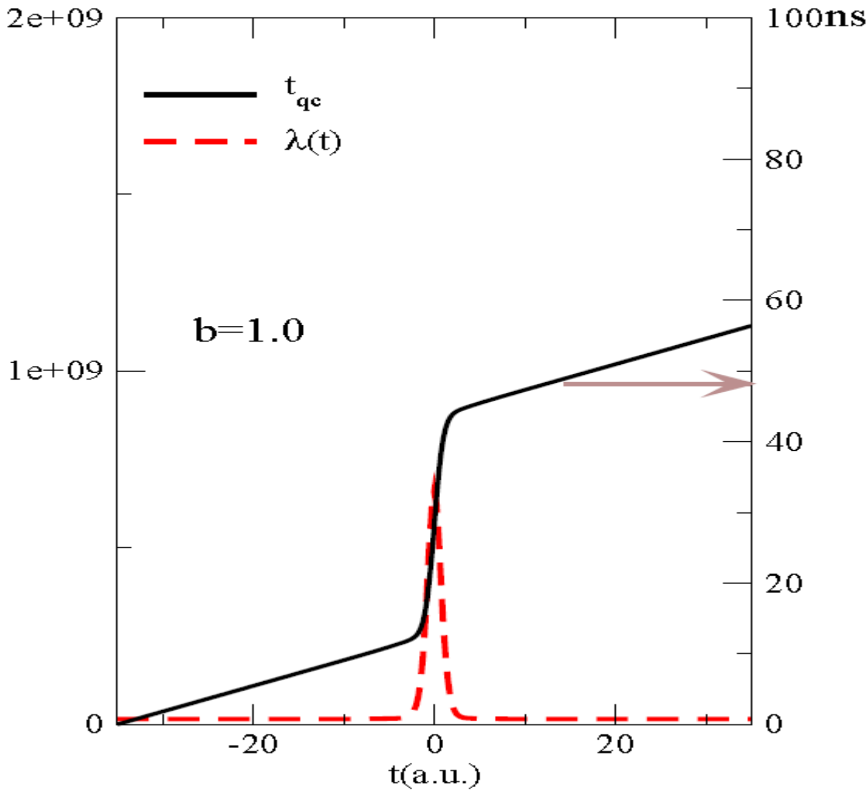
- $a(t)=e^{-iH't}\,a(-\infty)$

  $=e^{-i(H'/\lambda)(\lambda t)}\,a(-\infty)$

→ $a(t_{qc})=e^{-iH_{qc}t_{qc}}a(0)$

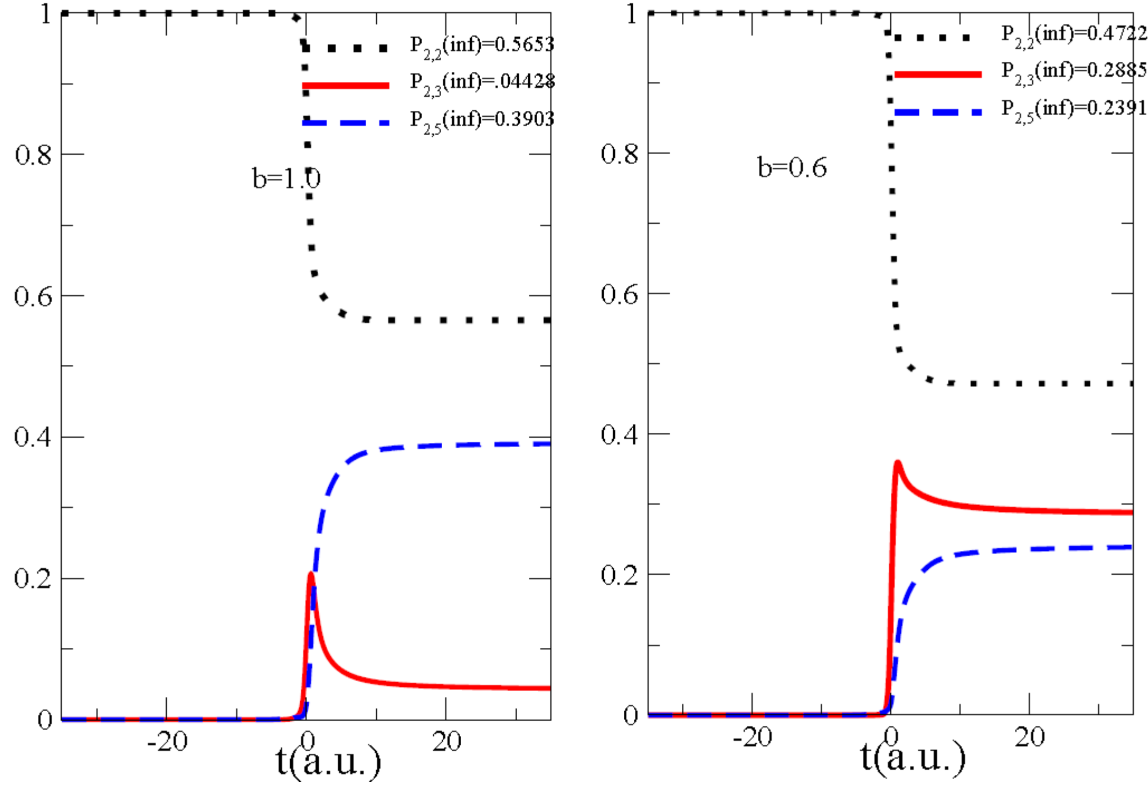
- $dt_{qc}/dt=\lambda$,

  $t_{qc}(-\infty)=0$



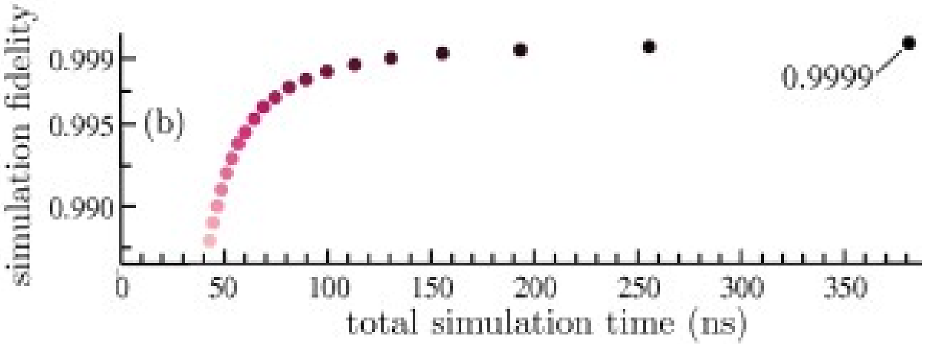
Quantum dynamics: Quantum Computer(2)

Scattering probabilities

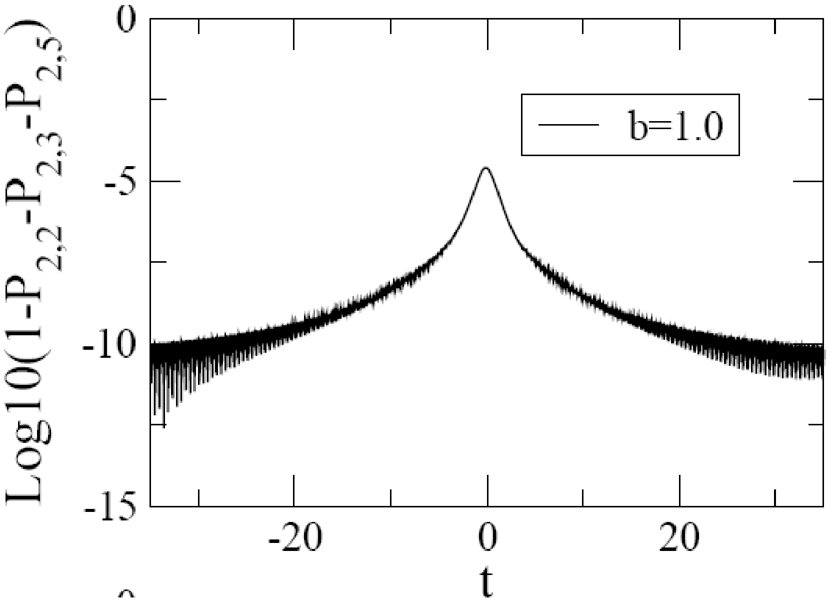


Quantum Computer: Fidelity and Leakage

Simulation fidelity



Leakage



Conclusion

- proposed a superconducting quantum simulator
- can simulate any random Hamiltonian

  -mapping error: zero
- example simulation of a molecular collision (electron orbital scattering)

  - 99% fidelity