Practical Quantum Computing:
Simulating physical system – motivation

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Plan

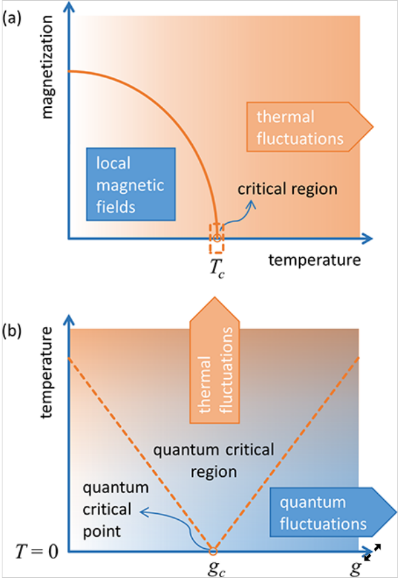
1. Quantum criticality

2. Quantum model of a magnet

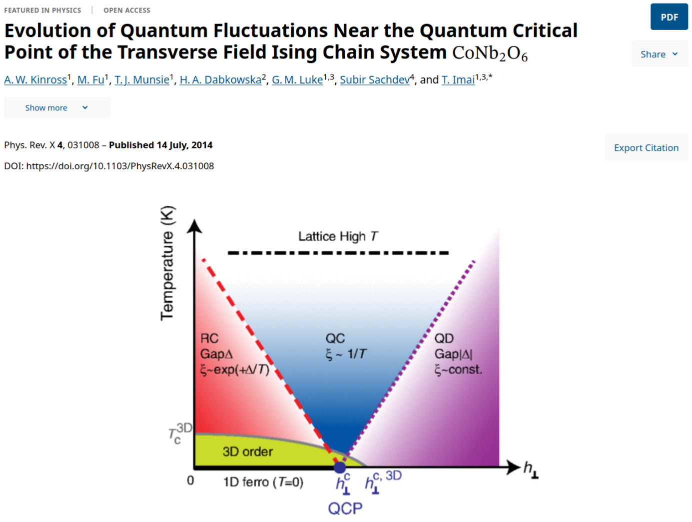
Introduction

- Analog model of quantum computation
- Circuit model of computation
- Simulating physical systems

Concept of quantum criticality



Physical realization



FEATURED IN PHYSICS | OPEN ACCESS

Evolution of Quantum Fluctuations Near the Quantum Critical Point of the Transverse Field Ising Chain System $\mathrm{CoNb_2O_6}$

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Transversal field Ising model

We consider a 1D chain of quantum spins

$$H = H_{zz} + H_x, \quad H_{zz} = -J \sum_i \hat{\sigma}_i^z \hat{\sigma}_{i+1}^z, \quad H_x = -h \sum_i \hat{\sigma}_i^x.$$

- z axis determined e.g. by crystal anisotropy
- magnetic field acts to “flip” magnetization direction
- parameters of the model: h, J (and temperature T)
- build-in competition (no common eigenbasis); quantum fluctuation parameter $g = h/J$

Limiting cases for a chain

- ordered phase for $h/J < 1$, two ground states related by spin-flip
- disordered phase for $h/J > 1$, nondegenerate ground state
- at $h = J$ quantum phase transition, gapless excitations; two-dimensional conformal field theory
- model maps to (interacting) fermions and can be solved exactly `https://scipost.org/SciPostPhysLectNotes.82`

Trotterization

Full quantum evolution is encoded by the unitary operator:

$$\exp(-itH) = \lim_{M\to\infty} \left[\exp(-i\tfrac{t}{M}H_x)\exp(-i\tfrac{t}{M}H_{zz})\right]^M$$

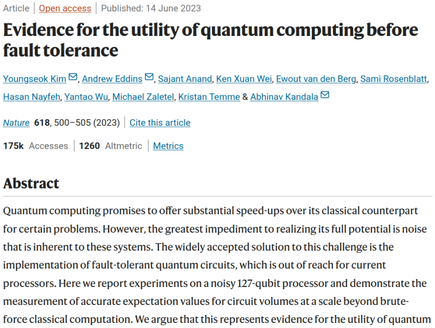
Let's denote $\Delta t = t/M$ and construct a circuit for the single step evolution:

$$U = [\exp(-i\Delta t H_x)\exp(-i\Delta t H_{zz})]$$

with a separated unitary sub-steps

$$U_x = \exp\left(ih\Delta t \sum_i \sigma_i^x\right), \qquad U_{zz} = \exp\left(iJ\Delta t \sum_i \sigma_i^z \sigma_{i+1}^z\right).$$

Current excitement



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Evidence for the utility of quantum computing before fault tolerance

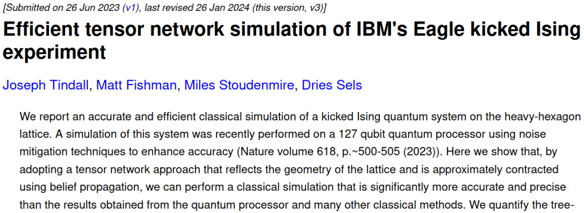
Youngseok Kim, Andrew Eddins, Sajant Anand, Ken Xuan Wei, Ewout van den Berg, Sami Rosenblatt, Hasan Nayfeh, Yantao Wu, Michael Zaletel, Kristan Temme & Abhinav Kandala

Nature **618**, 500–505 (2023) | Cite this article

175k Accesses | **1260** Altmetric | Metrics

Abstract

Quantum computing promises to offer substantial speed-ups over its classical counterpart for certain problems. However, the greatest impediment to realizing its full potential is noise that is inherent to these systems. The widely accepted solution to this challenge is the implementation of fault-tolerant quantum circuits, which is out of reach for current processors. Here we report experiments on a noisy 127-qubit processor and demonstrate the measurement of accurate expectation values for circuit volumes at a scale beyond brute-force classical computation. We argue that this represents evidence for the utility of quantum



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Efficient tensor network simulation of IBM's Eagle kicked Ising experiment

Joseph Tindall, Matt Fishman, Miles Stoudenmire, Dries Sels

We report an accurate and efficient classical simulation of a kicked Ising quantum system on the heavy-hexagon lattice. A simulation of this system was recently performed on a 127 qubit quantum processor using noise mitigation techniques to enhance accuracy (Nature volume 618, p.~500-505 (2023)). Here we show that, by adopting a tensor network approach that reflects the geometry of the lattice and is approximately contracted using belief propagation, we can perform a classical simulation that is significantly more accurate and precise than the results obtained from the quantum processor and many other classical methods. We quantify the tree-