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Quantum Computing for Fundamental Physics in NISQ era

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The dynamics of magnetization in spin chains

We are in the middle of 2nd Quantum Revolution:
Exploiting quantum mechanics for achieving computational/communication/technological advantage

Google's Quantum Computer

Ultimate goal: **Fault Tolerant Quantum Computing**

facilitating Error Correction (large overheads!)

At the moment **decoherence** still too detrimental

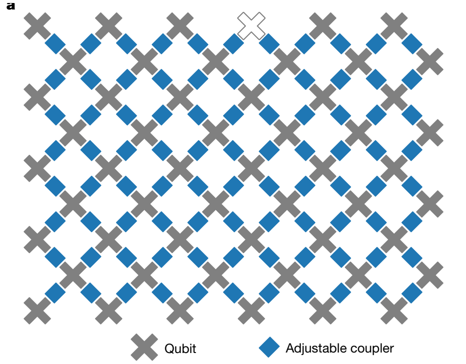
We are in the era of
NISQ (Noisy Intermediate Scale Quantum) devices

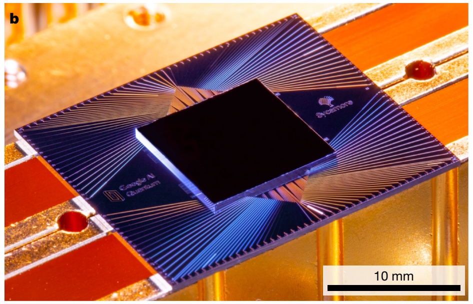
Can NISQ give us practical advantage/utility?

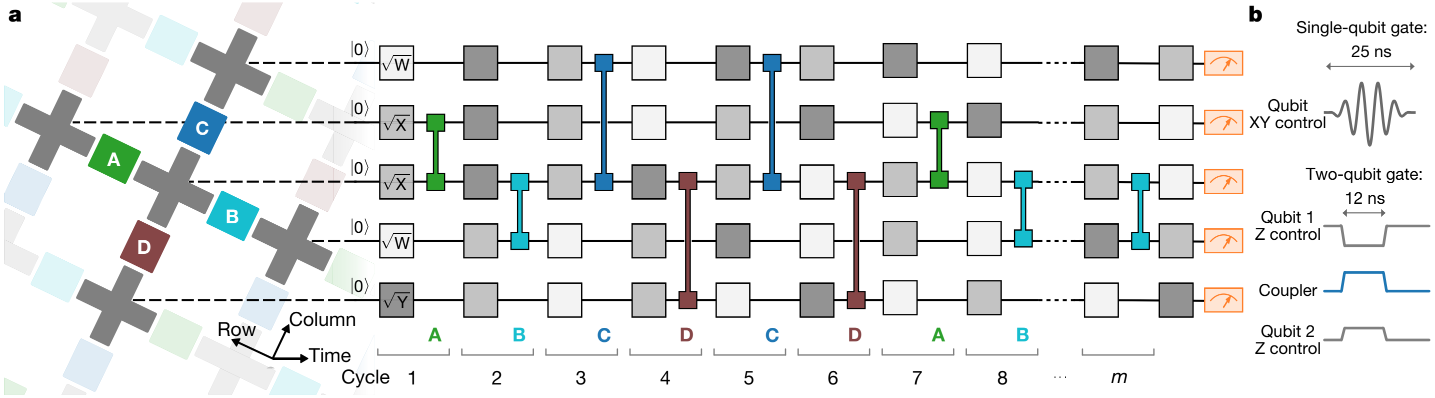
2019: The First Claim of Quantum Supremacy

Google Quantum AI simulation of RANDOM QUANUTM CIRCUITS

Nature **574**, 505 (2019)

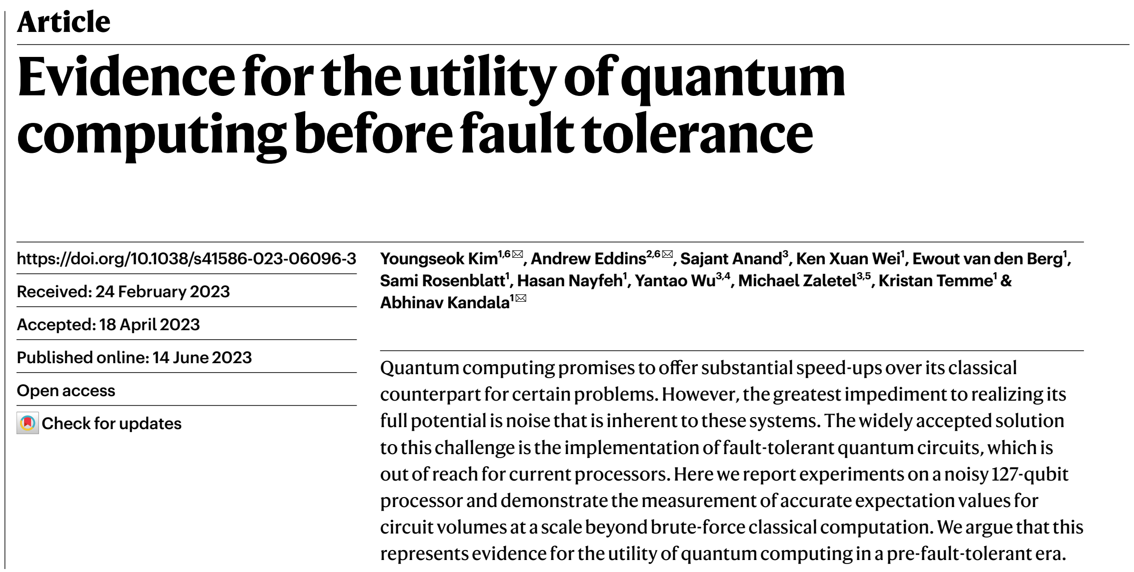






However, initial claims were soon challenged & refuted by improved classical algorithms!

Similar story repeated with IBM in 2023



Article

Evidence for the utility of quantum computing before fault tolerance

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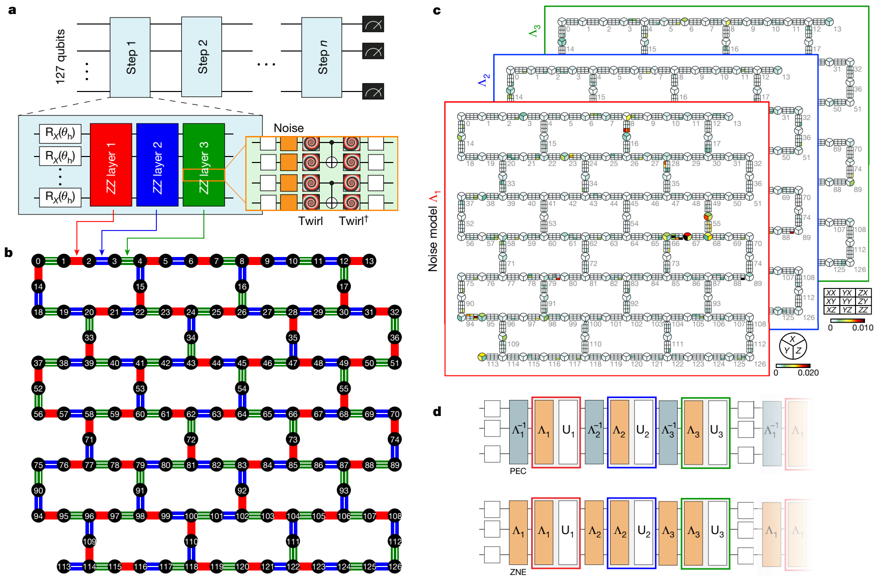
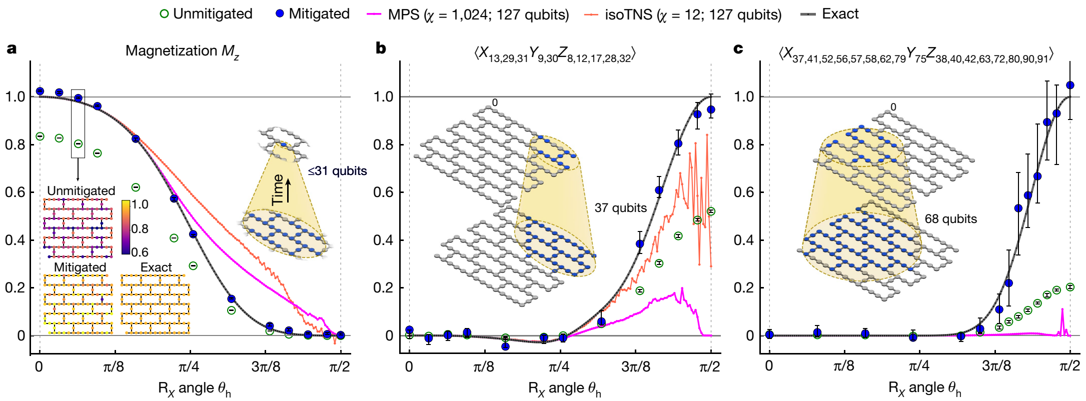
Accepted: 18 April 2023

Youngseok Kim[1,6]✉, Andrew Eddins[2,6]✉, Sajant Anand[3], Ken Xuan Wei[1], Ewout van den Berg[1], Sami Rosenblatt[1], Hasan Nayfeh[1], Yantao Wu[3,4], Michael Zaletel[3,5], Kristan Temme[1] & Abhinav Kandala[1]✉

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 computing in a pre-fault-tolerant era.





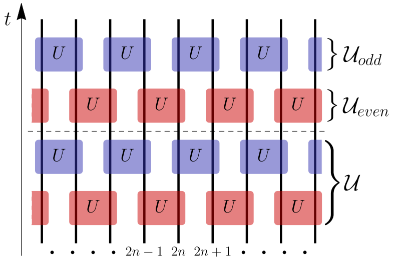
They consider dynamics of magnetization in 2D quantum Ising model with external field

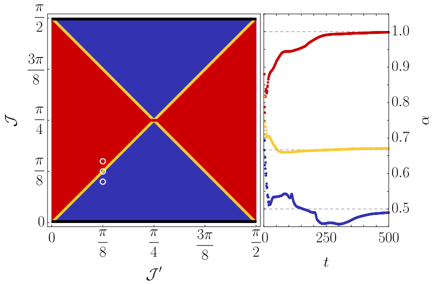
6months later classical tensor-networks algorithms were shown to perform just as good if not better

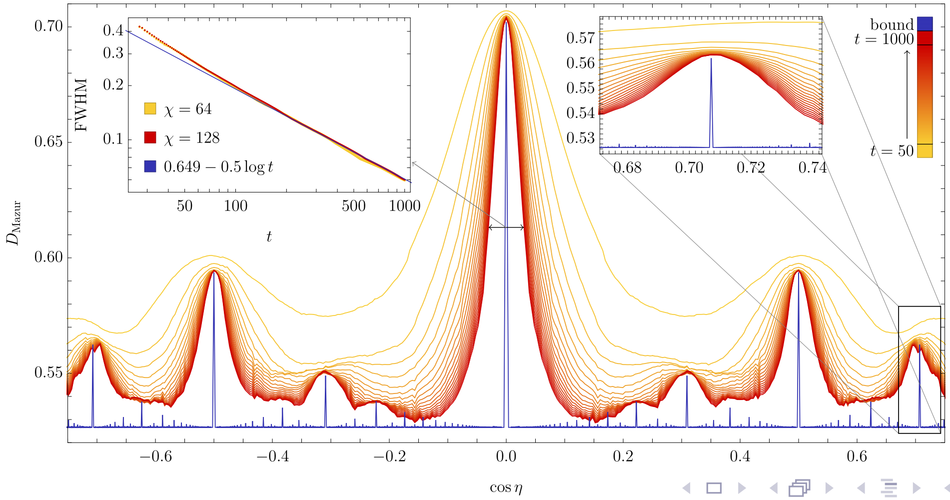
Quantum utility for simulation of simple quantum many-body systems with unusual/exotic dynamics/transport

Integrable Brickwall Circuits: Fantastic polygon for exotic many-body physics

[M. Vanicat, L. Zadnik and TP, PRL **121**, 030606(2018)]
[M. Ljubotina, L. Zadnik and TP, PRL **122**, 150605(2019)]







$$U = \exp\left(-i\mathcal{J}(\sigma^{\mathrm{x}}\otimes\sigma^{\mathrm{x}}+\sigma^{\mathrm{y}}\otimes\sigma^{\mathrm{y}}) - i\mathcal{J}'\sigma^{\mathrm{z}}\otimes\sigma^{\mathrm{z}}\right)$$

PHYSICAL REVIEW LETTERS **122,** 210602 (2019)

Kardar-Parisi-Zhang Physics in the Quantum Heisenberg Magnet

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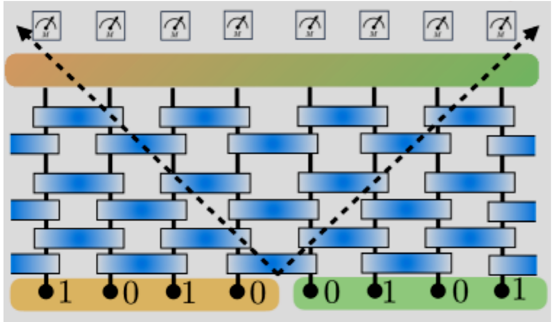
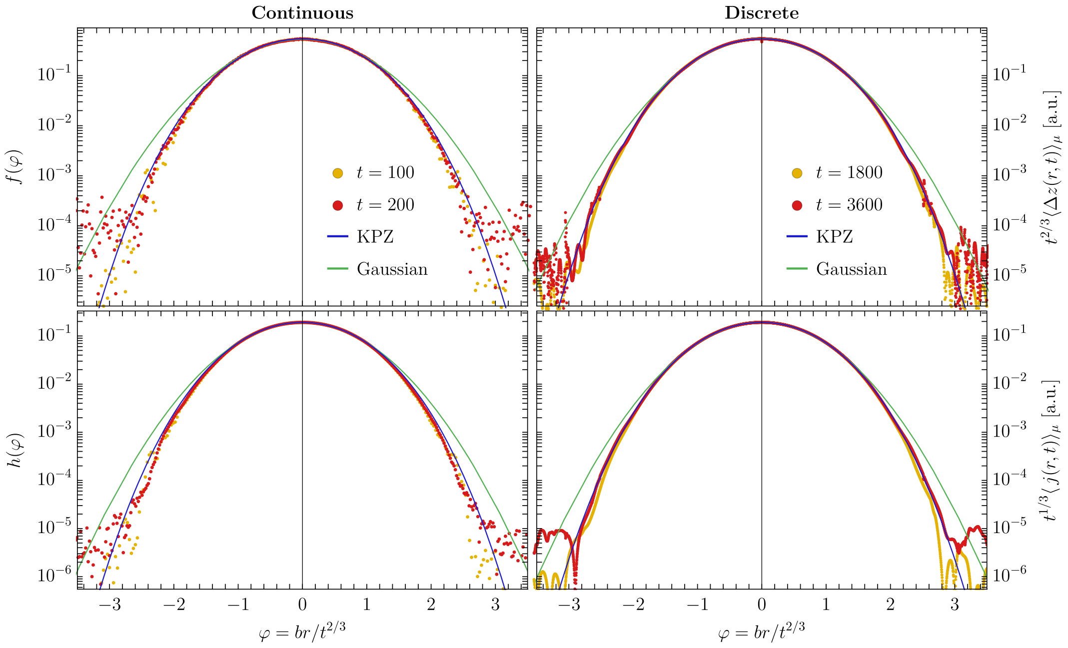
(Received 7 March 2019; published 31 May 2019)

Equilibrium spatiotemporal correlation functions are central to understanding weak nonequilibrium physics. In certain local one-dimensional classical systems with three conservation laws they show universal features. Namely, fluctuations around ballistically propagating sound modes can be described by the celebrated Kardar-Parisi-Zhang (KPZ) universality class. Can such a universality class be found also in quantum systems? By unambiguously demonstrating that the KPZ scaling function describes magnetization dynamics in the $SU(2)$ symmetric Heisenberg spin chain we show, for the first time, that this is so. We achieve that by introducing new theoretical and numerical tools, and make a puzzling observation that the conservation of energy does not seem to matter for the KPZ physics.

DOI: 10.1103/PhysRevLett.122.210602





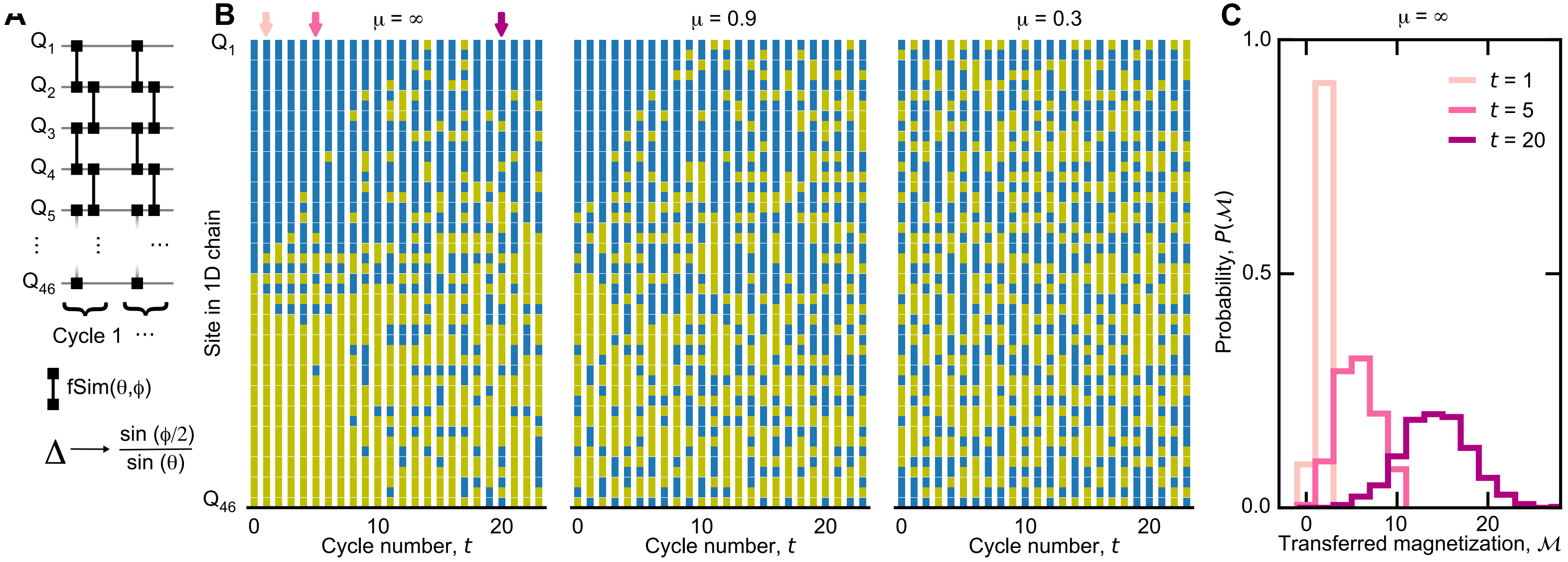
RESEARCH ARTICLE

QUANTUM SIMULATION

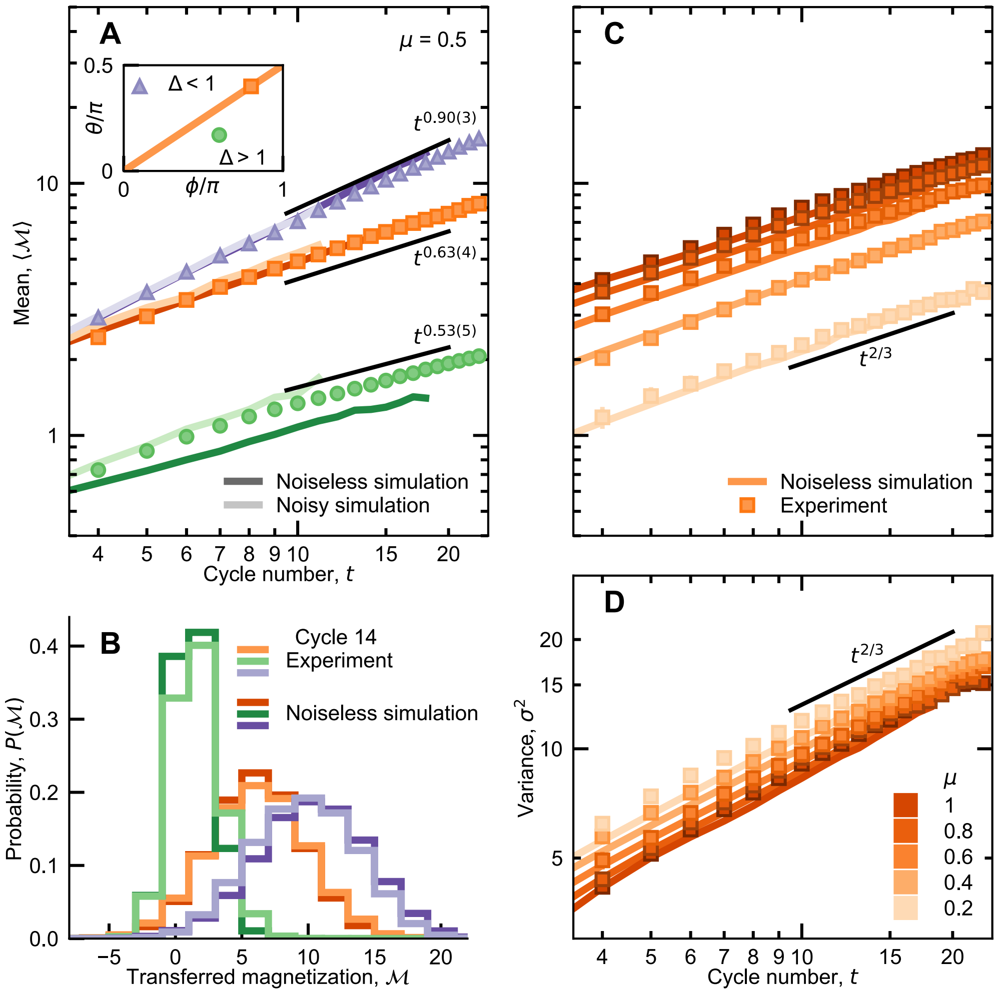
Science **384**, 48 (2024)

Dynamics of magnetization at infinite temperature in a Heisenberg spin chain

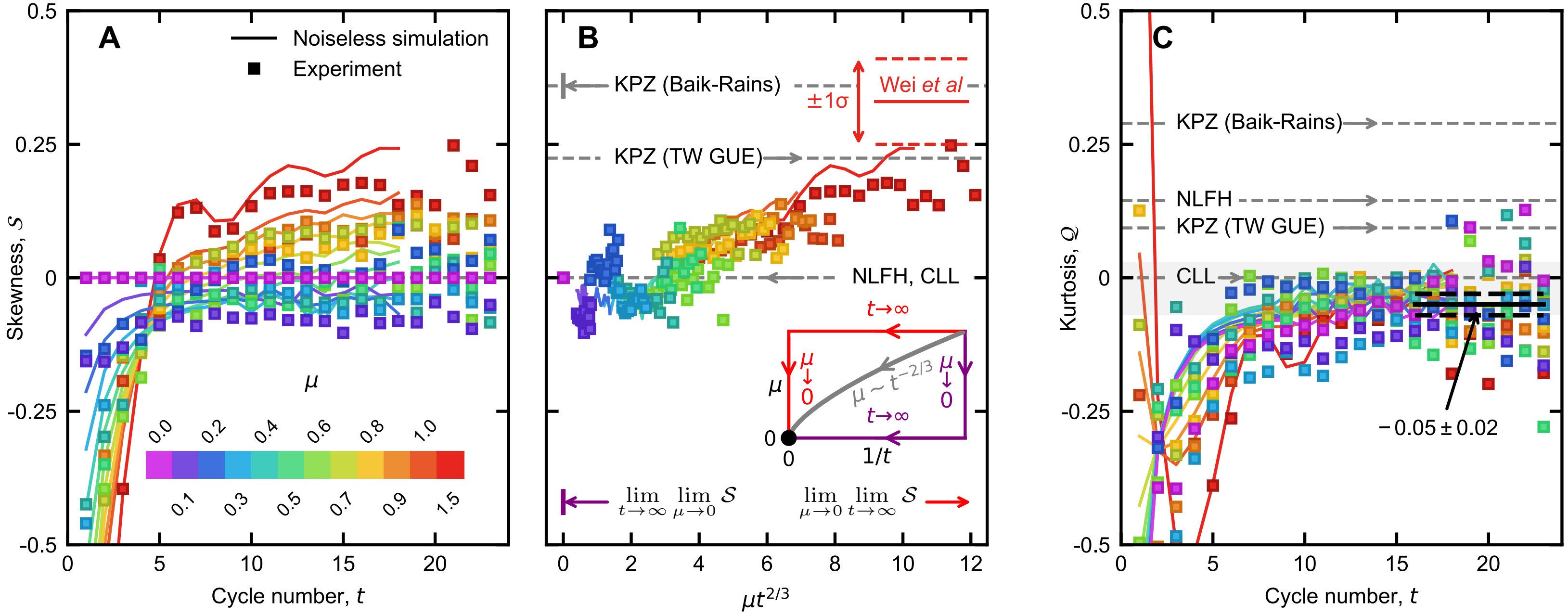
E. Rosenberg[1,2]†, T. I. Andersen[1]†, R. Samajdar[3,4], A. Petukhov[1], J. C. Hoke[5], D. Abanin[1], A. Bengtsson[1], I. K. Drozdov[1,6], C. Erickson[1], P. V. Klimov[1], X. Mi[1], A. Morvan[1], M. Neeley[1], C. Neill[1], R. Acharya[1], R. Allen[1], K. Anderson[1], M. Ansmann[1], F. Arute[1], K. Arya[1], A. Asfaw[1], J. Atalaya[1], J. C. Bardin[1,7], A. Bilmes[1], G. Bortoli[1], A. Bourassa[1], J. Bovaird[1], L. Brill[1], M. Broughton[1], B. B. Buckley[1], D. A. Buell[1], T. Burger[1], B. Burkett[1], N. Bushnell[1], J. Campero[1], H.-S. Chang[1], Z. Chen[1], B. Chiaro[1], D. Chik[1], J. Cogan[1], R. Collins[1], P. Conner[1], W. Courtney[1], A. L. Crook[1], B. Curtin[1], D. M. Debroy[1], A. Del Toro Barba[1], S. Demura[1], A. Di Paolo[1], A. Dunsworth[1], C. Earle[1], L. Faoro[1], E. Farhi [1], R. Fatemi[1], V. S. Ferreira[1], L. Flores Burgos[1,] E. Forati[1], A. G. Fowler[1], B. Foxen[1], G. Garcia[1], É. Genois[1], W. Giang[1], C. Gidney[1], D. Gilboa [1], M. Giustina[1], R. Gosula[1], A. Grajales Dau[1], J. A. Gross[1], S. Habegger[1], M. C. Hamilton[1,8], M. Hansen[1], M. P. Harrigan[1], S. D. Harrington[1], P. Heu[1], G. Hill[1], M. R. Hoffmann[1], S. Hong[1], T. Huang[1], A. Huff[1], W. J. Huggins[1], L. B. Ioffe[1], S. V. Isakov[1], J. Iveland[1], E. Jeffrey[1], Z. Jiang[1], C. Jones[1], P. Juhas[1], D. Kafri[1], T. Khattar[1], M. Khezri [1], M. Kieferová[1,9], S. Kim[1], A. Kitaev[1], A. R. Klots[1], A. N. Korotkov[1,10], F. Kostritsa[1], J. M. Kreikebaum[1], D. Landhuis[1], P. Laptev[1], K.-M. Lau[1], L. Laws[1], J. Lee[1,11], K. W. Lee[1], Y. D. Lensky[1], B. J. Lester[1], A. T. Lill[1], W. Liu[1], A. Locharla[1], S. Mandrà[1], O. Martin[1], S. Martin[1], J. R. McClean[1], M. McEwen[1], S. Meeks[1], K. C. Miao[1], A. Mieszala[1], S. Montazeri[1], R. Movassagh[1], W. Mruczkiewicz[1], A. Nersisyan[1], M. Newman[1], J. H. Ng[1], A. Nguyen[1], M. Nguyen[1], M. Y. Niu[1], T. E. O'Brien[1], S. Omonije[1], A. Opremcak[1], R. Potter[1], L. P. Pryadko[12], C. Quintana[1], D. M. Rhodes[1], C. Rocque[1], N. C. Rubin[1], N. Saei [1], D. Sank[1], K. Sankaragomathi[1], K. J. Satzinger[1], H. F. Schurkus[1], C. Schuster[1], M. J. Shearn[1], A. Shorter[1], N. Shutty[1], V. Shvarts[1], V. Sivak[1], J. Skruzny[1], W. Clarke Smith[1], R. D. Somma[1], G. Sterling[1], D. Strain[1] M. Szalay[1], D. Thor[1], A. Torres[1], G. Vidal[1], B. Villalonga[1], C. Vollgraff Heidweiller[1], T. White[1], B. W. K. Woo[1], C. Xing[1], Z. Jamie Yao[1], P. Yeh[1], J. Yoo[1], G. Young[1], A. Zalcman[1], Y. Zhang[1], N. Zhu[1], N. Zobrist[1], H. Neven[1], R. Babbush[1], D. Bacon[1], S. Boixo[1], J. Hilton[1], E. Lucero[1], A. Megrant[1], J. Kelly[1], Y. Chen[1], V. Smelyanskiy[1], V. Khemani[5], S. Gopalakrishnan[3], T. Prosen[13]*, P. Roushan[1]*



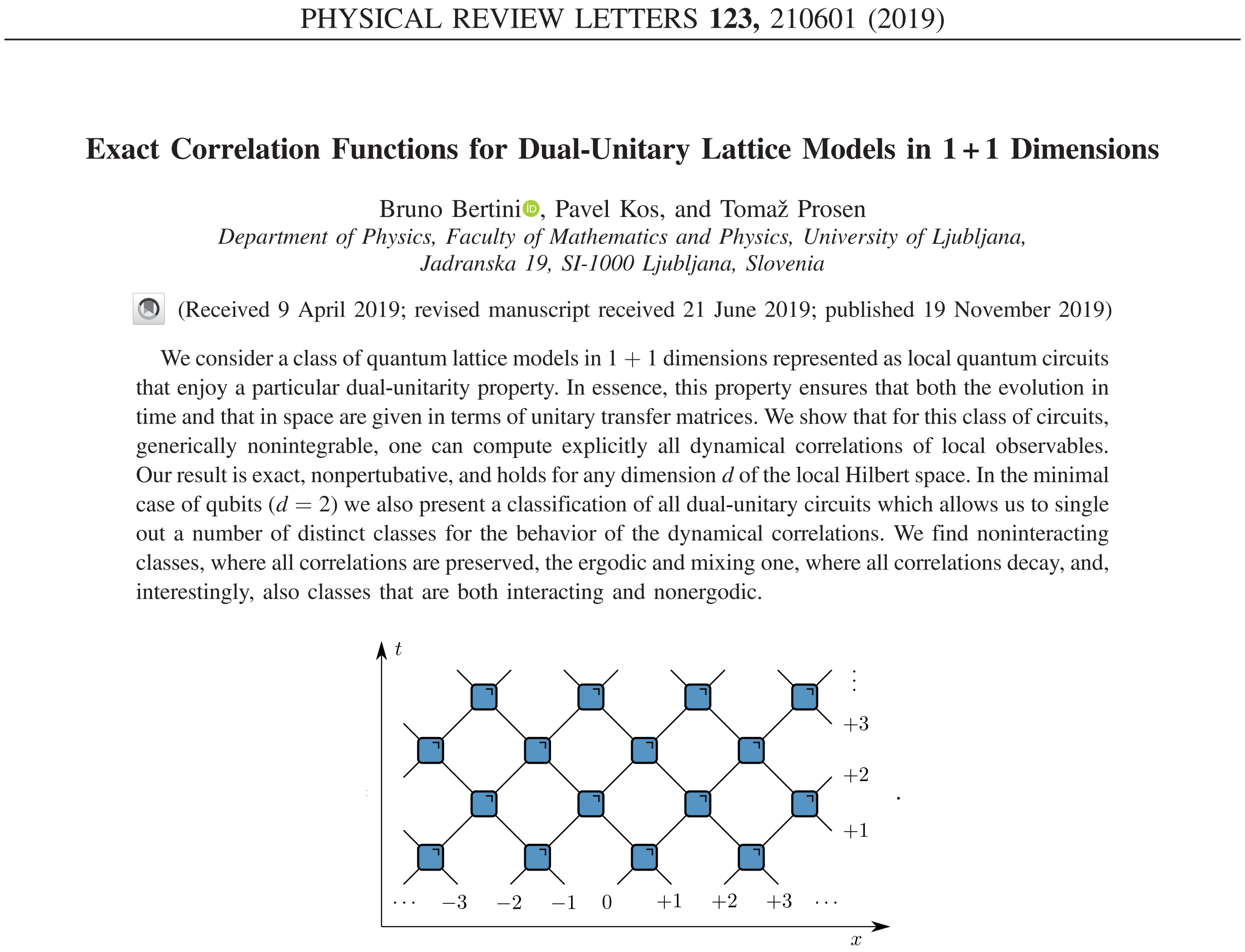
Mean and variance of transfered magnetization



Higher moments - fluctuation statistics



DUAL UNITARY CIRCUITS: Exactly solvable many-body chaos



PHYSICAL REVIEW LETTERS **123,** 210601 (2019)

Exact Correlation Functions for Dual-Unitary Lattice Models in 1 + 1 Dimensions

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(Received 9 April 2019; revised manuscript received 21 June 2019; published 19 November 2019)

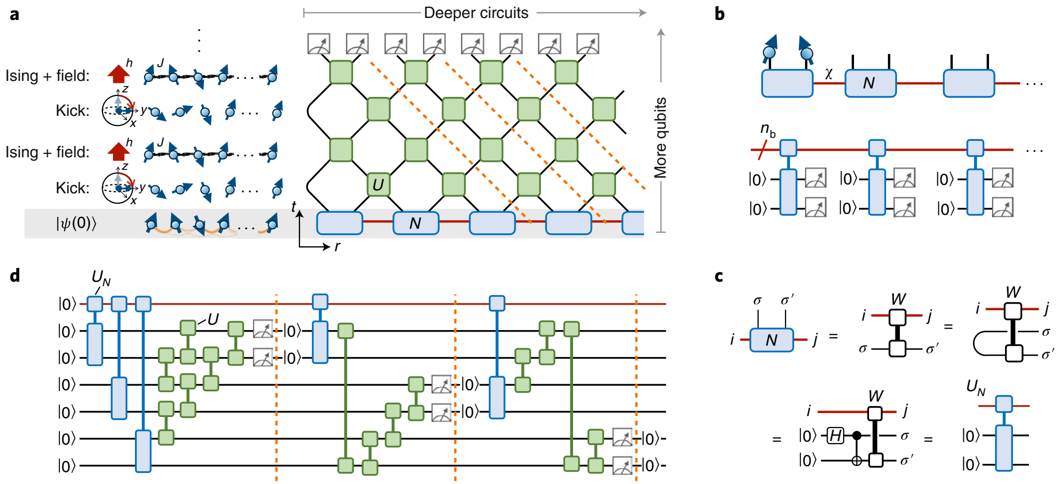
We consider a class of quantum lattice models in $1 + 1$ dimensions represented as local quantum circuits that enjoy a particular dual-unitarity property. In essence, this property ensures that both the evolution in time and that in space are given in terms of unitary transfer matrices. We show that for this class of circuits, generically nonintegrable, one can compute explicitly all dynamical correlations of local observables. Our result is exact, nonpertubative, and holds for any dimension d of the local Hilbert space. In the minimal case of qubits ($d = 2$) we also present a classification of all dual-unitary circuits which allows us to single out a number of distinct classes for the behavior of the dynamical correlations. We find noninteracting classes, where all correlations are preserved, the ergodic and mixing one, where all correlations decay, and, interestingly, also classes that are both interacting and nonergodic.

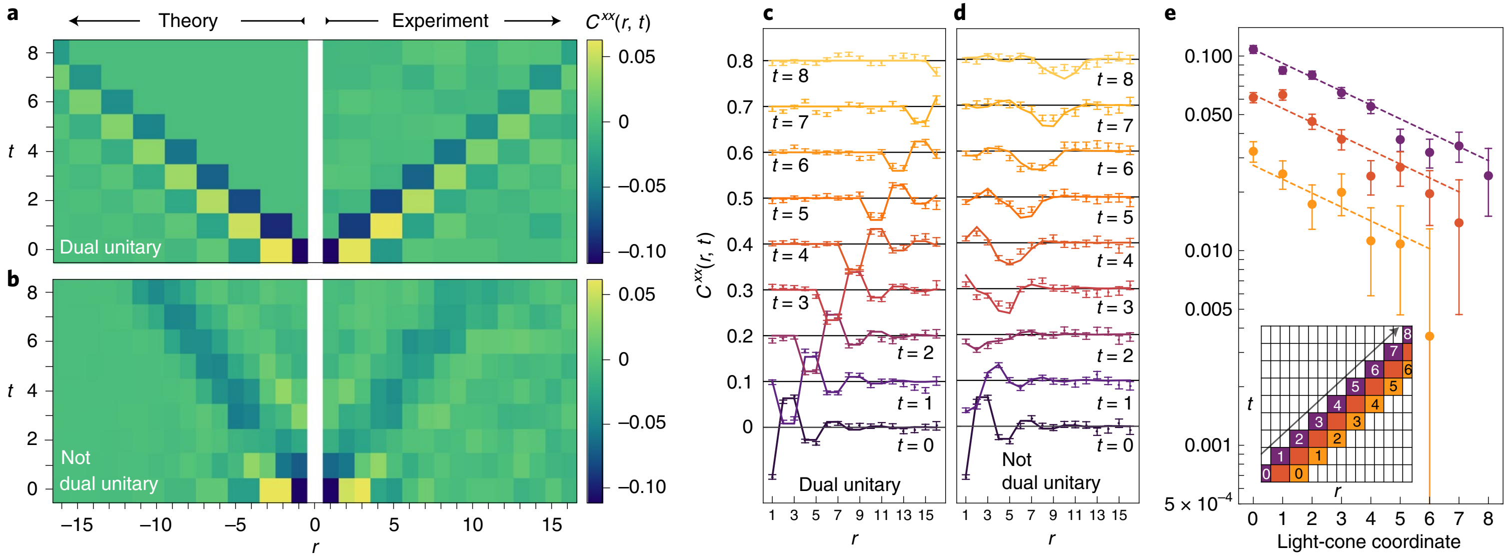
Nature Phys. **18**, 1074 (2022)

ARTICLES
https://doi.org/10.1038/s41567-022-01689-7
nature physics

Holographic dynamics simulations with a trapped-ion quantum computer

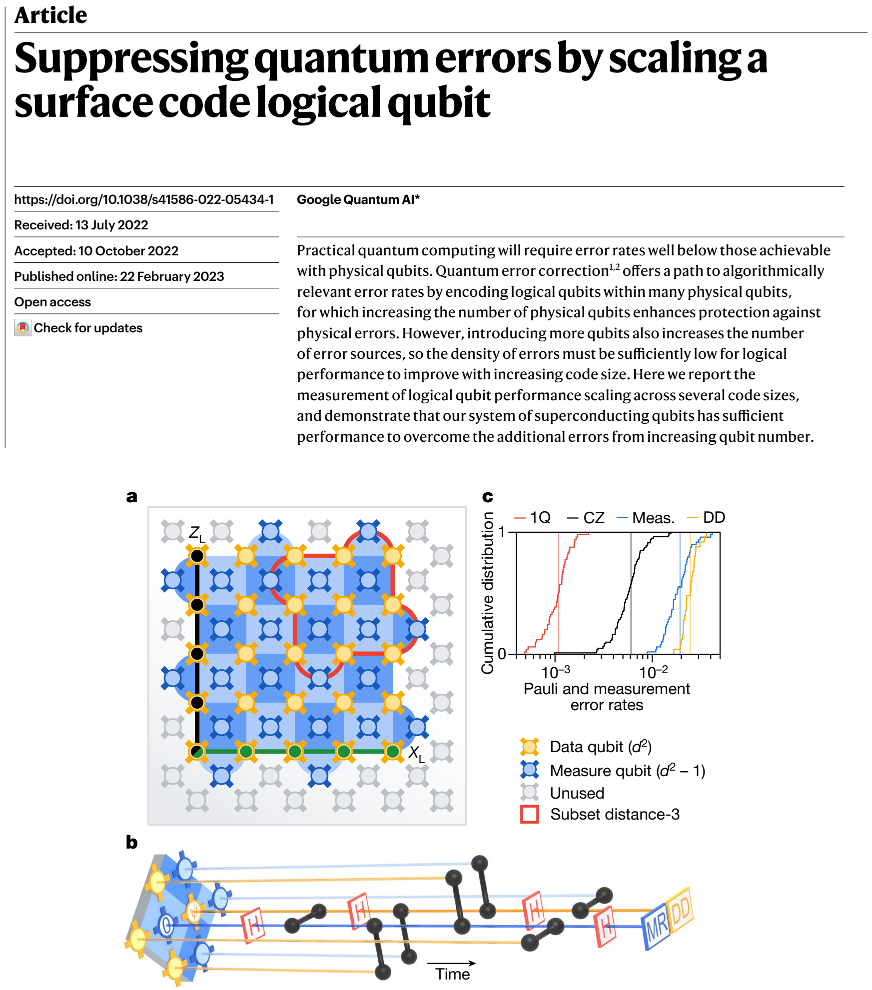
Eli Chertkov[1,2], Justin Bohnet[1], David Francois[1], John Gaebler[1], Dan Gresh[1], Aaron Hankin[1], Kenny Lee[1,5], David Hayes[1], Brian Neyenhuis[1], Russell Stutz[1], Andrew C. Potter[3,4] and Michael Foss-Feig[1]





First steps towards fault tolerance: Demonstration of stable logical qubits

Nature **614**, 677 (2023)



Article

Suppressing quantum errors by scaling a surface code logical qubit

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Open access

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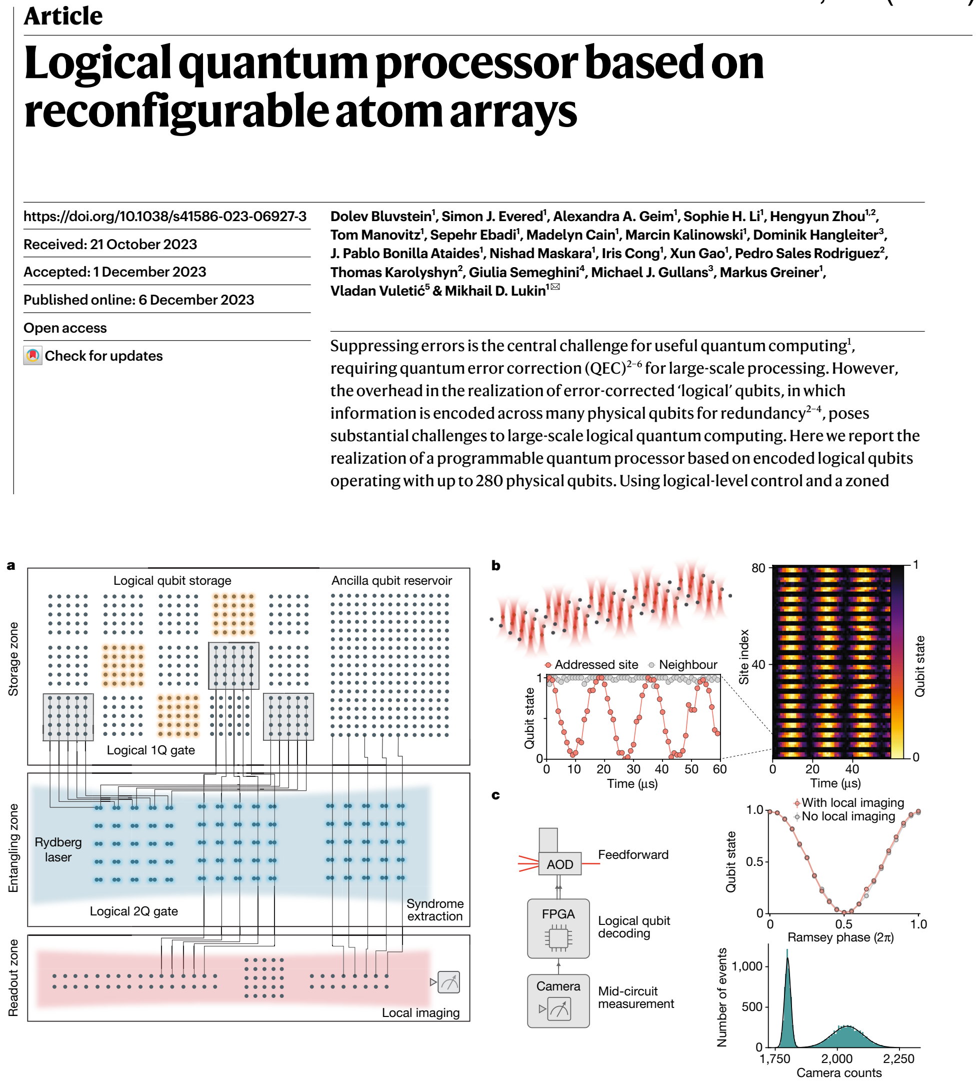
Google Quantum AI*

Practical quantum computing will require error rates well below those achievable with physical qubits. Quantum error correction[1,2] offers a path to algorithmically relevant error rates by encoding logical qubits within many physical qubits, for which increasing the number of physical qubits enhances protection against physical errors. However, introducing more qubits also increases the number of error sources, so the density of errors must be sufficiently low for logical performance to improve with increasing code size. Here we report the measurement of logical qubit performance scaling across several code sizes, and demonstrate that our system of superconducting qubits has sufficient performance to overcome the additional errors from increasing qubit number.

Nature **626**, 58 (2024)



Article

Logical quantum processor based on reconfigurable atom arrays

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Check for updates

Dolev Bluvstein[1], Simon J. Evered[1], Alexandra A. Geim[1], Sophie H. Li[1], Hengyun Zhou[1,2], Tom Manovitz[1], Sepehr Ebadi[1], Madelyn Cain[1], Marcin Kalinowski[1], Dominik Hangleiter[3], J. Pablo Bonilla Ataides[1], Nishad Maskara[1], Iris Cong[1], Xun Gao[1], Pedro Sales Rodriguez[2], Thomas Karolyshyn[2], Giulia Semeghini[4], Michael J. Gullans[3], Markus Greiner[1], Vladan Vuletić[5] & Mikhail D. Lukin[1]✉

Suppressing errors is the central challenge for useful quantum computing[1], requiring quantum error correction (QEC)[2–6] for large-scale processing. However, the overhead in the realization of error-corrected 'logical' qubits, in which information is encoded across many physical qubits for redundancy[2–4], poses substantial challenges to large-scale logical quantum computing. Here we report the realization of a programmable quantum processor based on encoded logical qubits operating with up to 280 physical qubits. Using logical-level control and a zoned

Quantum Computers are approaching break-even point as compared to best classical computers/algorithms, for specific tasks, mainly related to dynamical phenomena in fundamental physics

Fault tolerant QC is still sometime in future, but no fundamental obstacles are foreseen, and when done, there will be no limit..

Funding

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