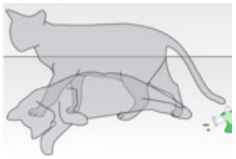
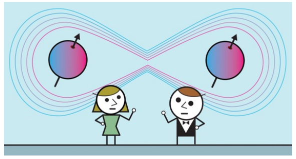
Quantum Computing Is Hot

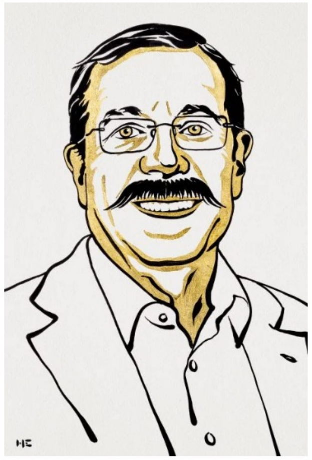


Quantum computing utilizes quantum properties such as superposition & entanglement for computation



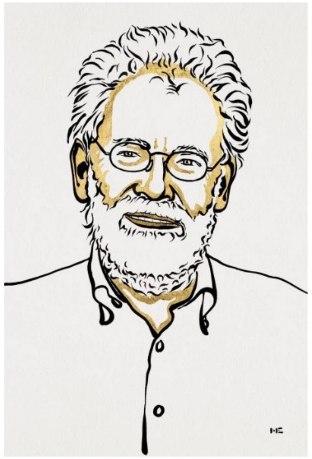
The Nobel Prize in Physics 2022

It's entanglement!



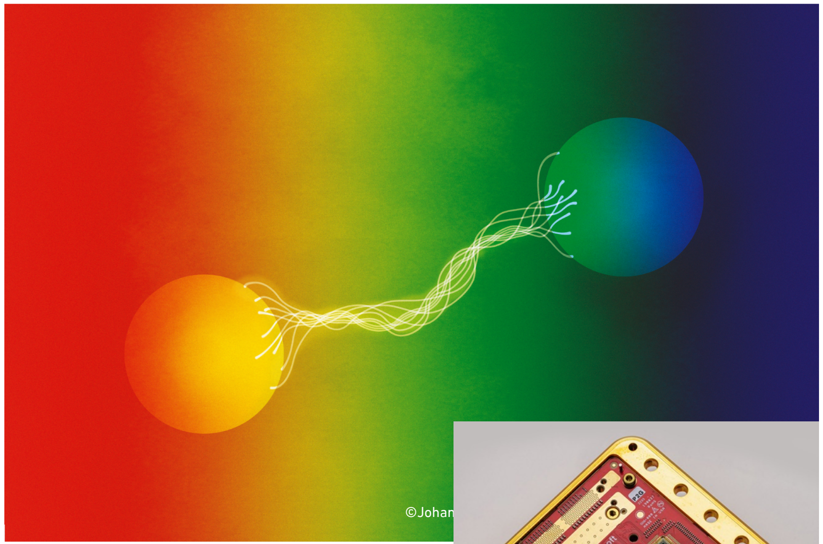
Ill. Niklas Elmehed © Nobel Prize Outreach
Alain Aspect
Prize share: 1/3

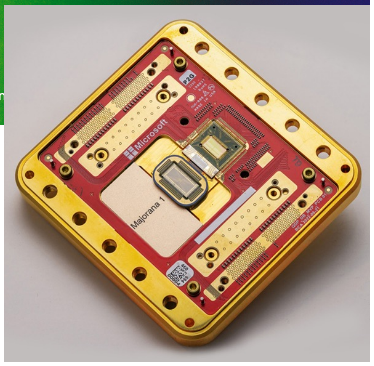
Ill. Niklas Elmehed © Nobel Prize Outreach
John F. Clauser
Prize share: 1/3



Ill. Niklas Elmehed © Nobel Prize Outreach
Anton Zeilinger
Prize share: 1/3

The Nobel Prize in Physics 2022 was awarded jointly to Alain Aspect, John F. Clauser and Anton Zeilinger "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"



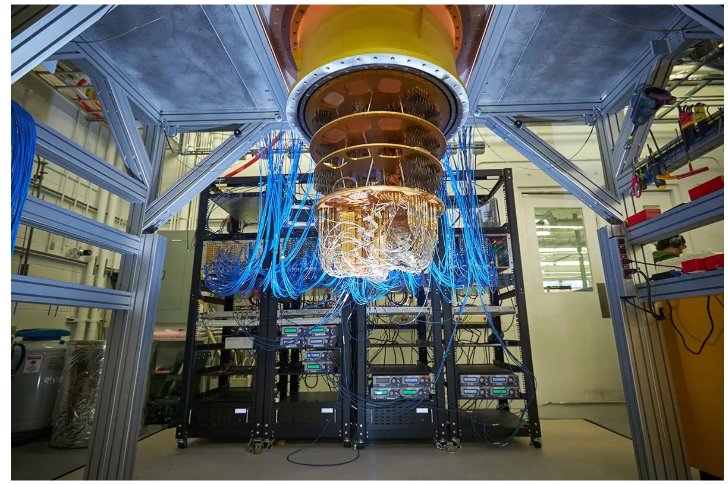


cf. Microsoft announced Majorana 1 quantum chip (Feb. 19, '25)

https://news.microsoft.com/azure-quantum

Quantum Computing Is Now

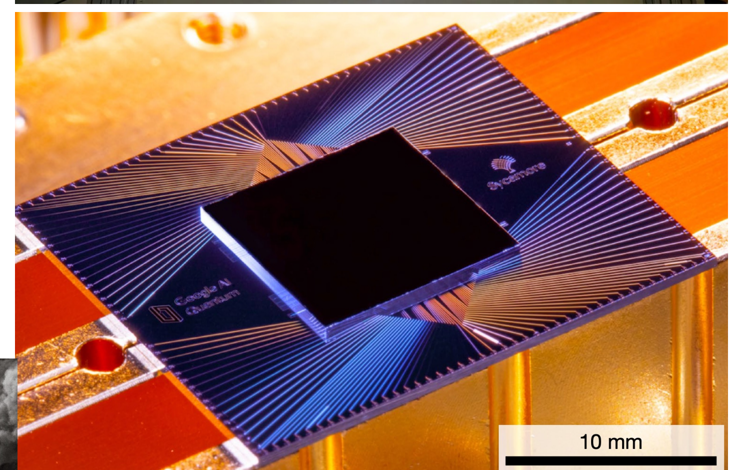
- **U.S. Congress (Dec. 21, ’18) signed National Quantum Initiative Act to ensure leadership in quantum computing & its applications**
- **Quantum supremacy (*i.e.*, quantum computer is faster than the fastest** supercomputer) was **demonstrated by Google**
  Arute, Martinis, *et al*., *Nature* **574**, 505 (’19)
- **Google’s Sycamore quantum computer consumed 26 kilowatts of power to outperform the 13 megawatts Summit supercomputer at Oak Ridge National Lab, *i.e.*, 500 times more energy efficient**



9,216-CPU & 27,648-GPU Summit

<

Fast & frugal



54-qubit Google Sycamore

Quantum Computing Gets Hotter

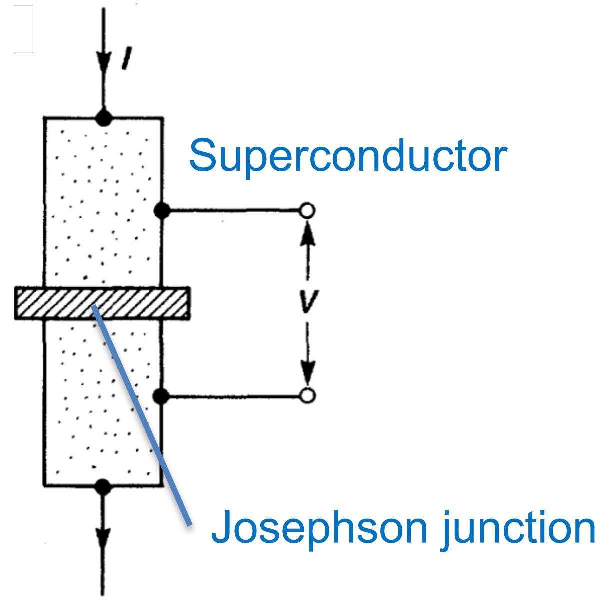
Nobel Prize in Physics 2025

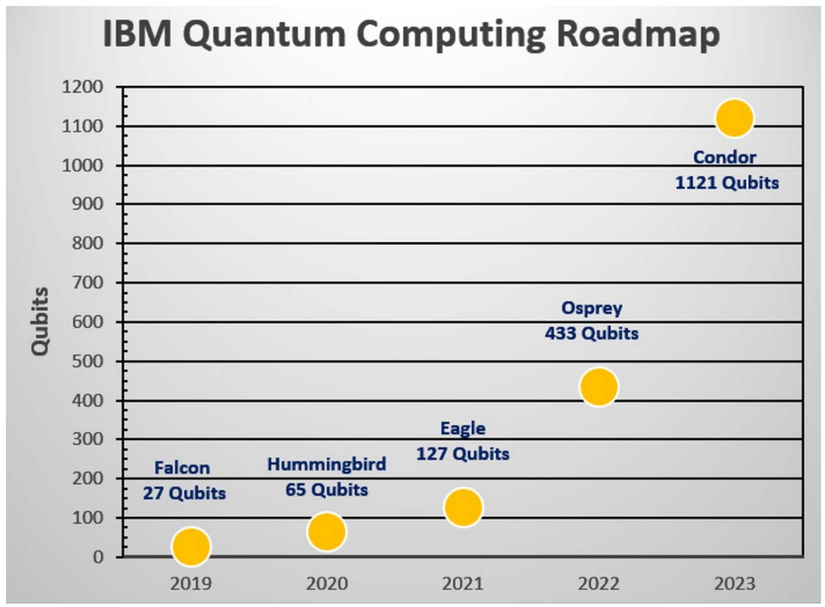
Ill. Niklas Elmehed © Nobel Prize Outreach
John Clarke
Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach
Michel H. Devoret
Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach
John M. Martinis
Prize share: 1/3

The Nobel Prize in Physics 2025 was awarded jointly to John Clarke, Michel H. Devoret and John M. Martinis "for the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit"





Foundation of superconducting quantum circuits

It’s Molecular & Quantum Dynamics!

Phase difference of wave functions across a Josephson junction

$$I = I_0 \sin\delta \quad \textbf{and} \quad \frac{d\delta}{dt} = \frac{2e}{\hbar} V$$

$$\frac{d\delta}{dt} = \frac{2e}{\hbar}\frac{Q}{C}$$

Charge

Capacitance

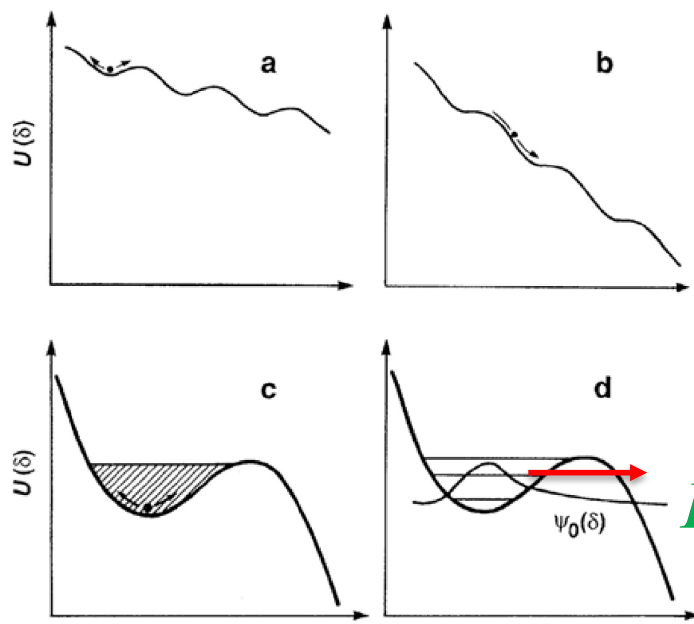
$$\frac{\hbar}{2e} C \frac{d\delta}{dt} = Q$$

$$\frac{\hbar}{2e} C \frac{d^2}{dt^2}\delta = \frac{dQ}{dt}$$

$$I = I_0 \sin\delta + \frac{\hbar}{2e} C \frac{d^2}{dt^2}\delta$$

$$\overbrace{\frac{\hbar}{2e} C}^{\text{mass } M} \frac{d^2}{dt^2}\delta = I - I_0 \sin\delta = -\frac{\partial}{\partial\delta}\left(\overbrace{-I\delta - I_0\cos\delta}^{\text{potential } U(\delta)}\right)$$

It’s MD!



It’s tunneling in QD!

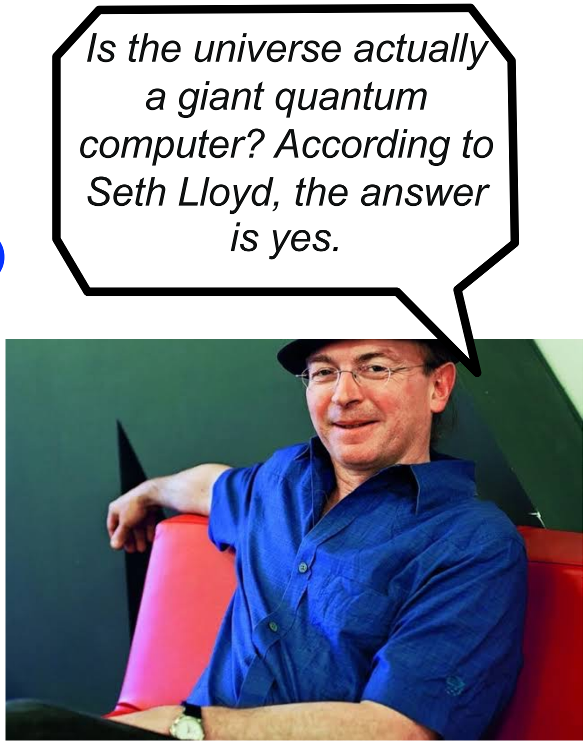
https://www.nobelprize.org/uploads/2025/10/advanced-physicsprize2025.pdf

Quantum Computational Science

- **An exciting scientific application of quantum computers is as a universal simulator of quantum many-body dynamics, as envisioned by Richard Feynman** *Int. J. Theor. Phys*. 21, 467 ('82)

- **Seth Lloyd provided concrete algorithms and analysis** *Science* 273, 1073 ('96)
  Watch Seth's movie: https://www.youtube.com/watch?v=EMzKshc6x2M

  https://www.amazon.com/Programming-Universe-Quantum-Computer-Scientist-ebook/dp/B000GCFBP6



- **Success in simulating *static* properties of quantum systems (*i.e.*, ground-state energy of small molecules)**
  Aspuru-Guzik *et al*., *Science* 309, 1704 ('05)

- **Challenge: Simulate quantum many-body *dynamics* on current-to-near-future noisy intermediate-scale quantum (NISQ) computers**
  J. Preskill, *Quantum* 2, 79 ('18)

- **Second edition of *Feynman Lectures on Computation* (2023) added a section on "Simulating quantum dynamics" by John Preskill** *arXiv*:2106.10522 ('21)

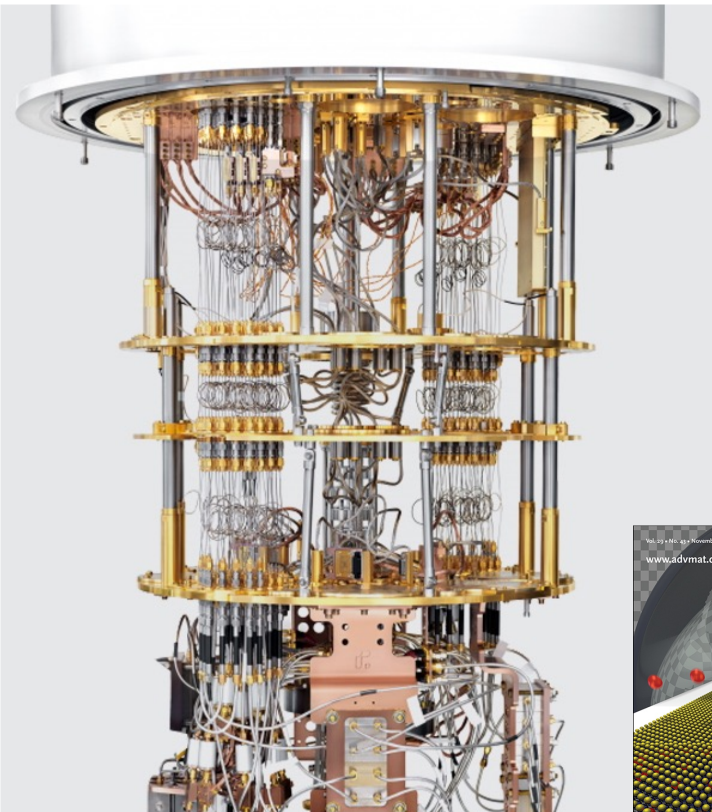
https://www.amazon.com/Feynman-Lectures-Computation-Anniversary-Frontiers/dp/0367857332

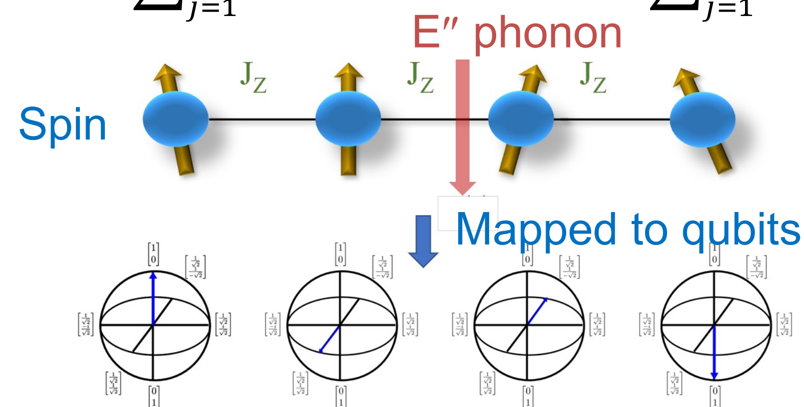
Quantum Computing of Magnetism

- **Simulated quantum many-body dynamics of magnetic spins on IBM's Q16 Melbourne & Rigetti's Aspen quantum processors**

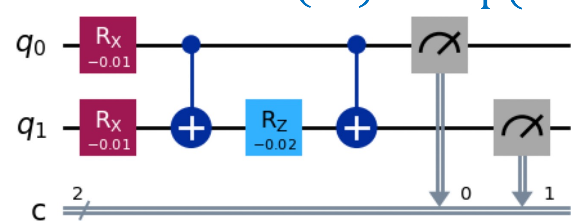
L. Bassman *et al.*, *Phys. Rev.* 101, 184305 ('20)

$$H(t) = -J_z \sum_{j=1}^{N-1} \boldsymbol{\sigma}_z^j \boldsymbol{\sigma}_z^{j+1} - \varepsilon_{ph} \sin(\omega_{ph} t) \sum_{j=1}^{N} \boldsymbol{\sigma}_x^j$$



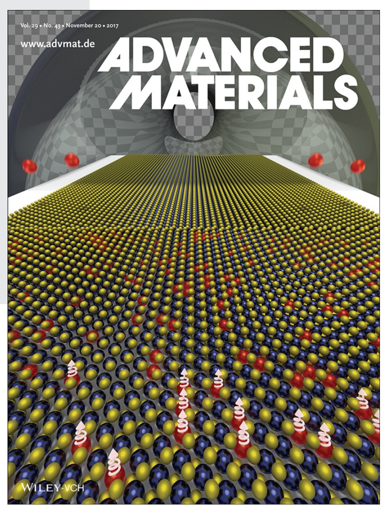


Quantum circuit: $U(\Delta t) = \exp(-iH\Delta t)$



Quantum (Python) program

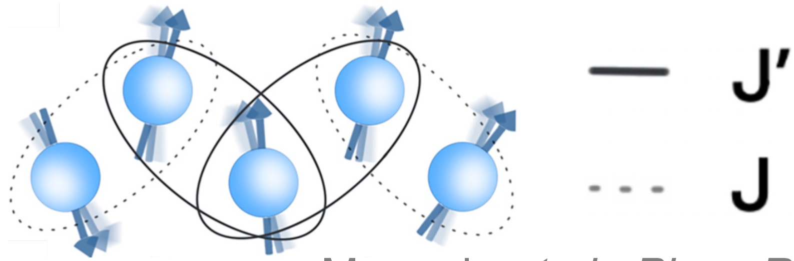
```
circ.rx(-2*dt*B, 0)
circ.rx(-2*dt*B, 1)
circ.cx(0, 1)
circ.rz(-2*dt*J, 1)
circ.cx(0, 1)
```



Re-doped $MoSe_2$

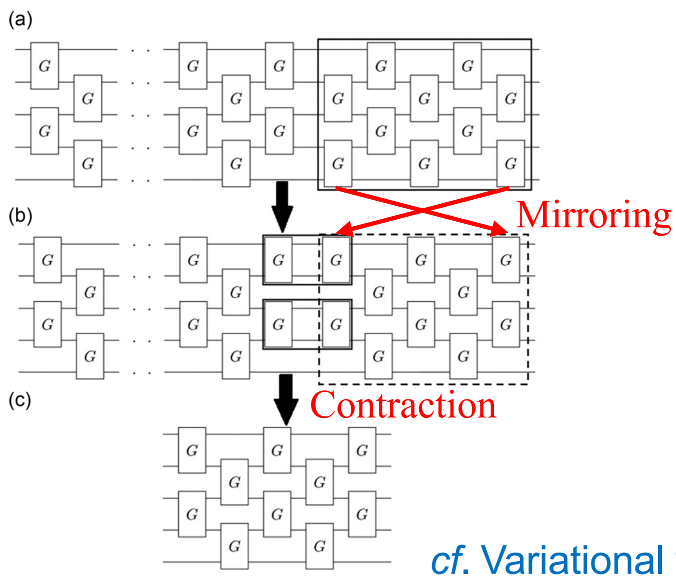
Topological Quantum Dynamics & Beyond

Quantum spin chain

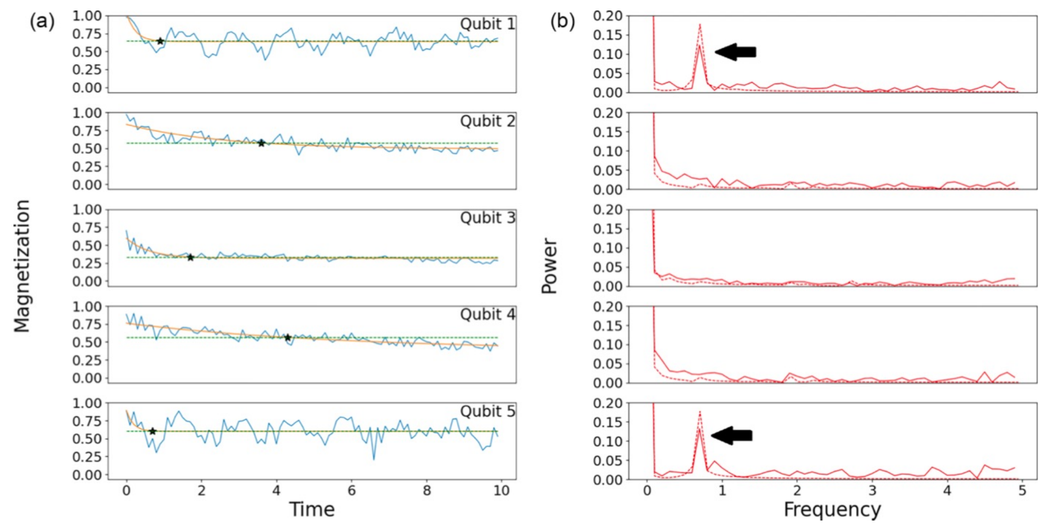


Mercado *et al*., *Phys. Rev. B* **110**, 075116 ('24)

Constant-depth quantum circuit



Topological surface mode



cf. Variational fast-forwarding, Yang-Baxter equation

- **DCR/MSA paradigm allows exponentially hard topological quantum many-body dynamics to be offloaded from Exaflop/s supercomputers to quantum processing units (QPU), realizing *quantum-centric supercomputing (QCSC)*** Alexeev *et al*., *FGCS* **160**, 666 ('24)