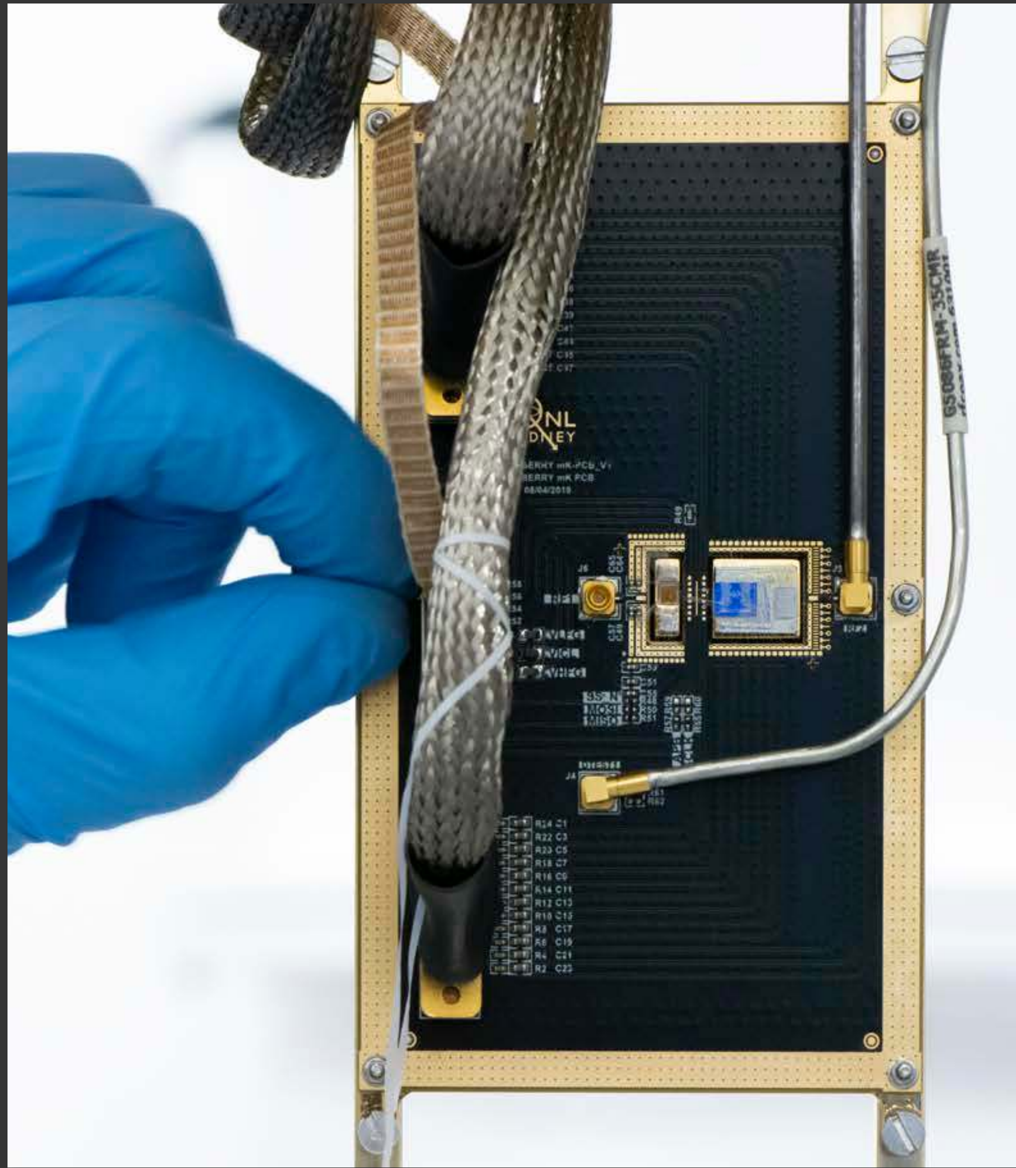
If only we could control them:

Challenges and Opportunities in Scaling-up Quantum Computers

David Reilly

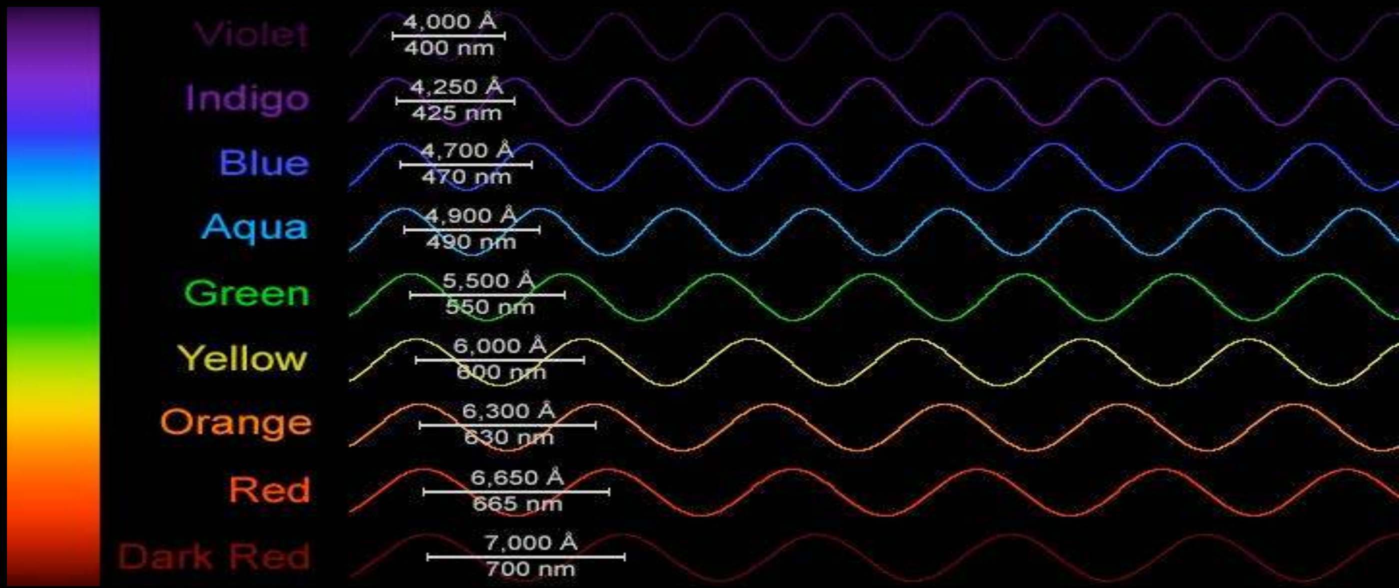
www.microsoft.com/quantum/



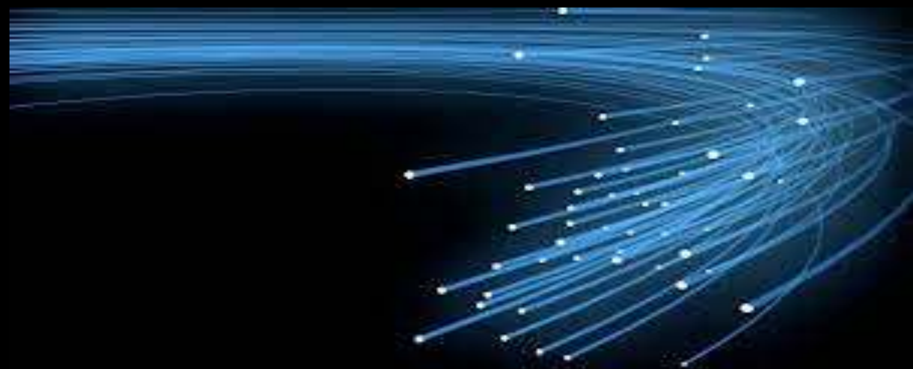
Microsoft

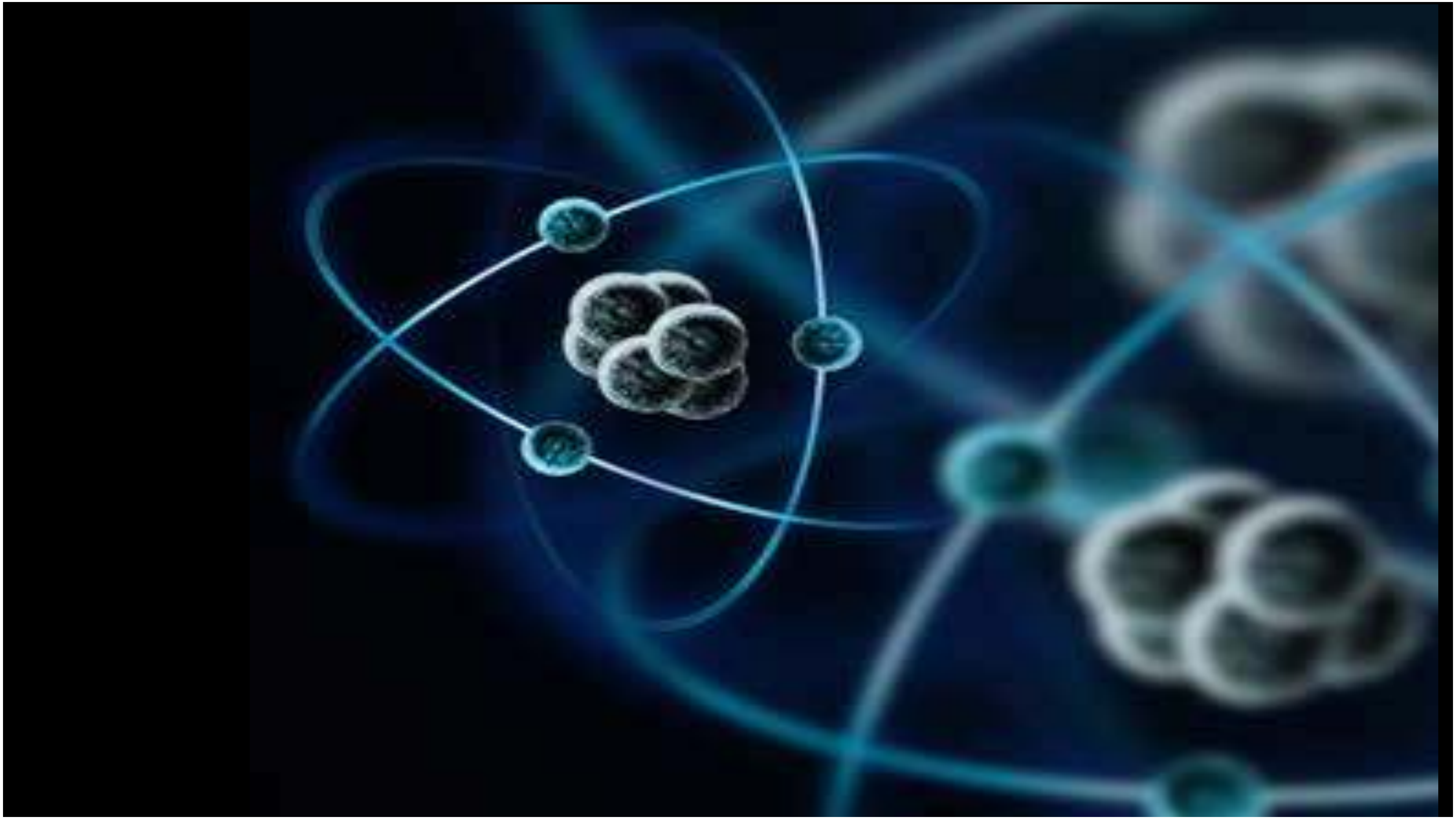
THE UNIVERSITY OF SYDNEY

Light waves



Light particles (photons)





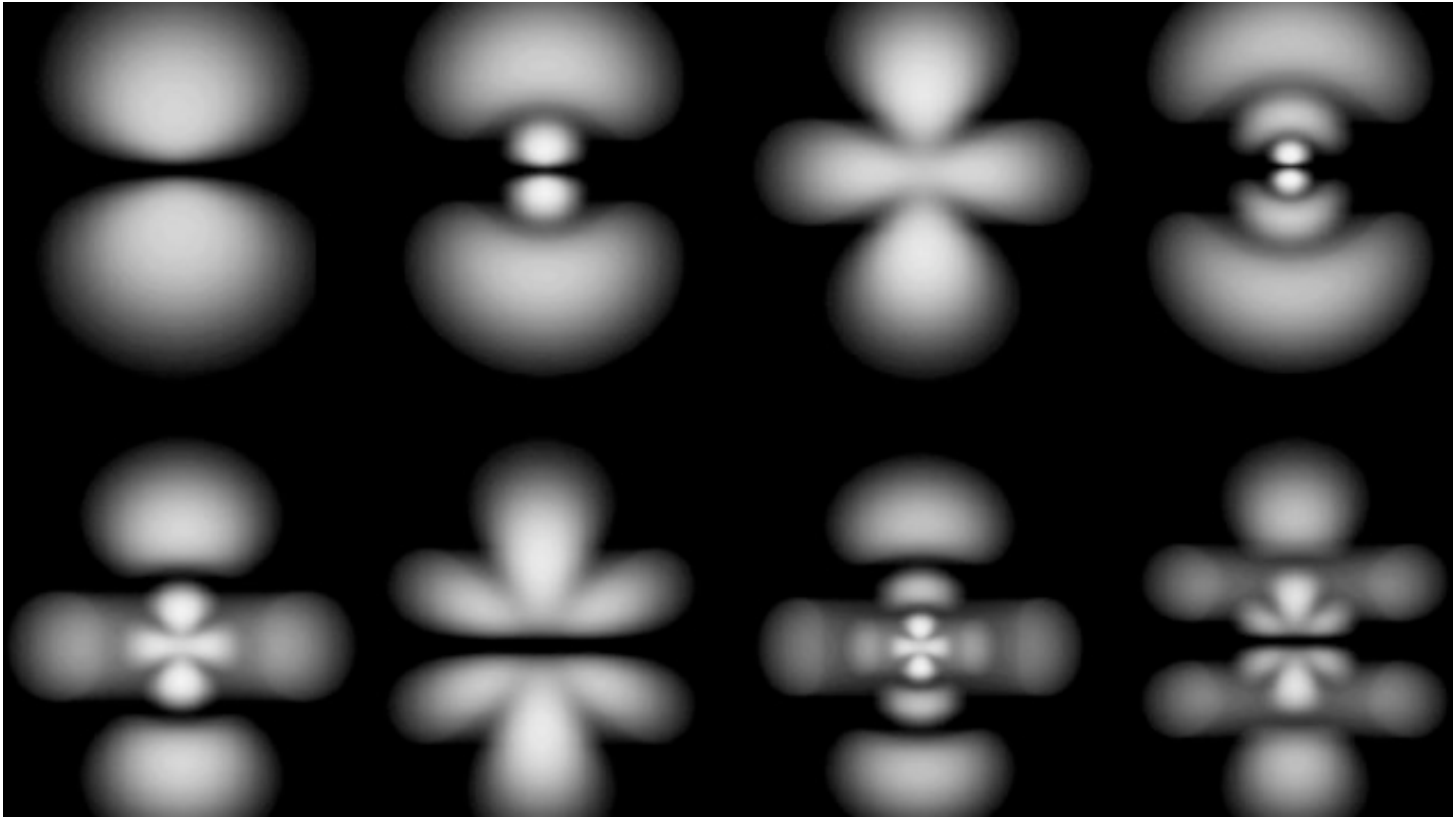
Louis-Victor-Pierre-Raymond,
7th duc de Broglie

	particle	wave
Light	✓	✓
Matter	✓	? ✓

"He has lifted a corner of the veil that shrouds the Old One." –Einstein (Thesis Report).

Ph.D Awarded 1924.

Experimentally demonstrated in 1927. Nobel Prize for Physics 1929.

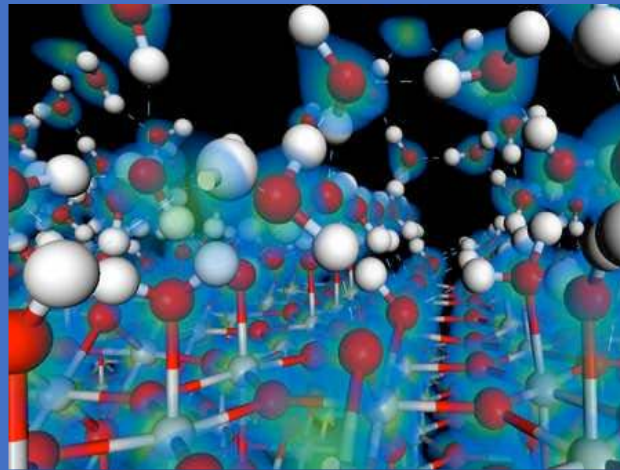



Search the web and Windows
11:37 AM
10/6/2015

Quantum Technologies

Sensing & Imaging

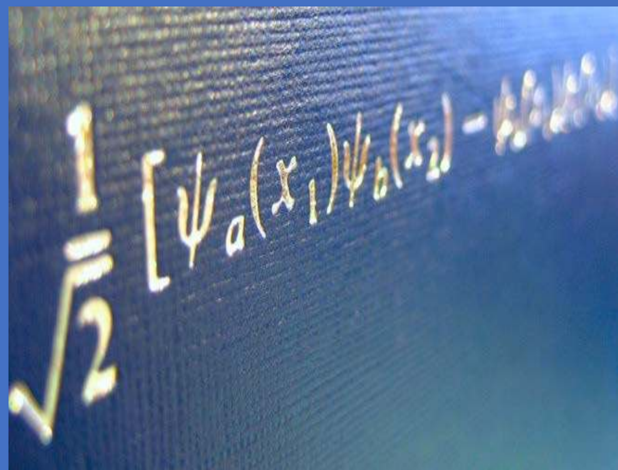
Computing



Simulation

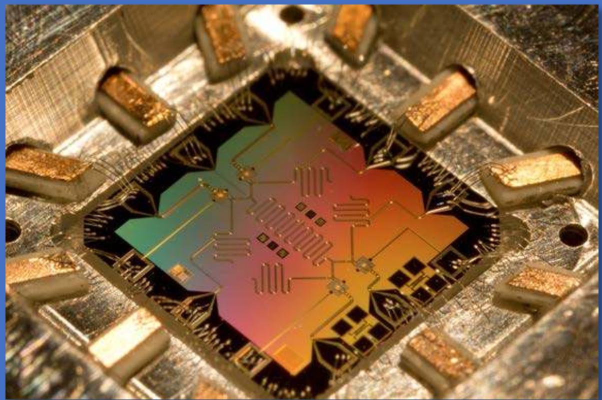
Metrology

Secure communication

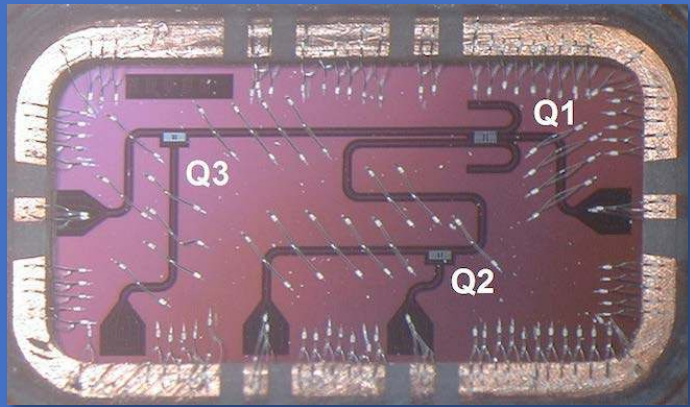


New Physics

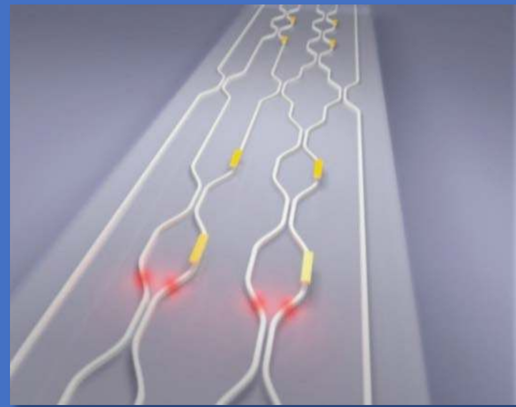
Convergence of Qubit Platforms



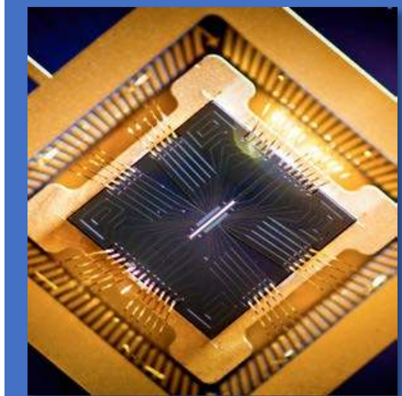
Superconducting qubits



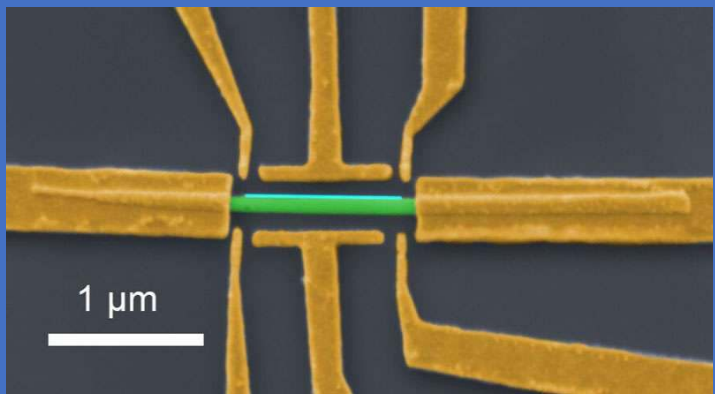
Superconducting qubits



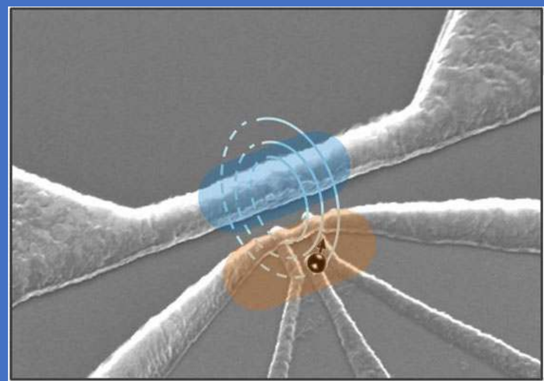
Photonic Qubits



Surface Ion Trap



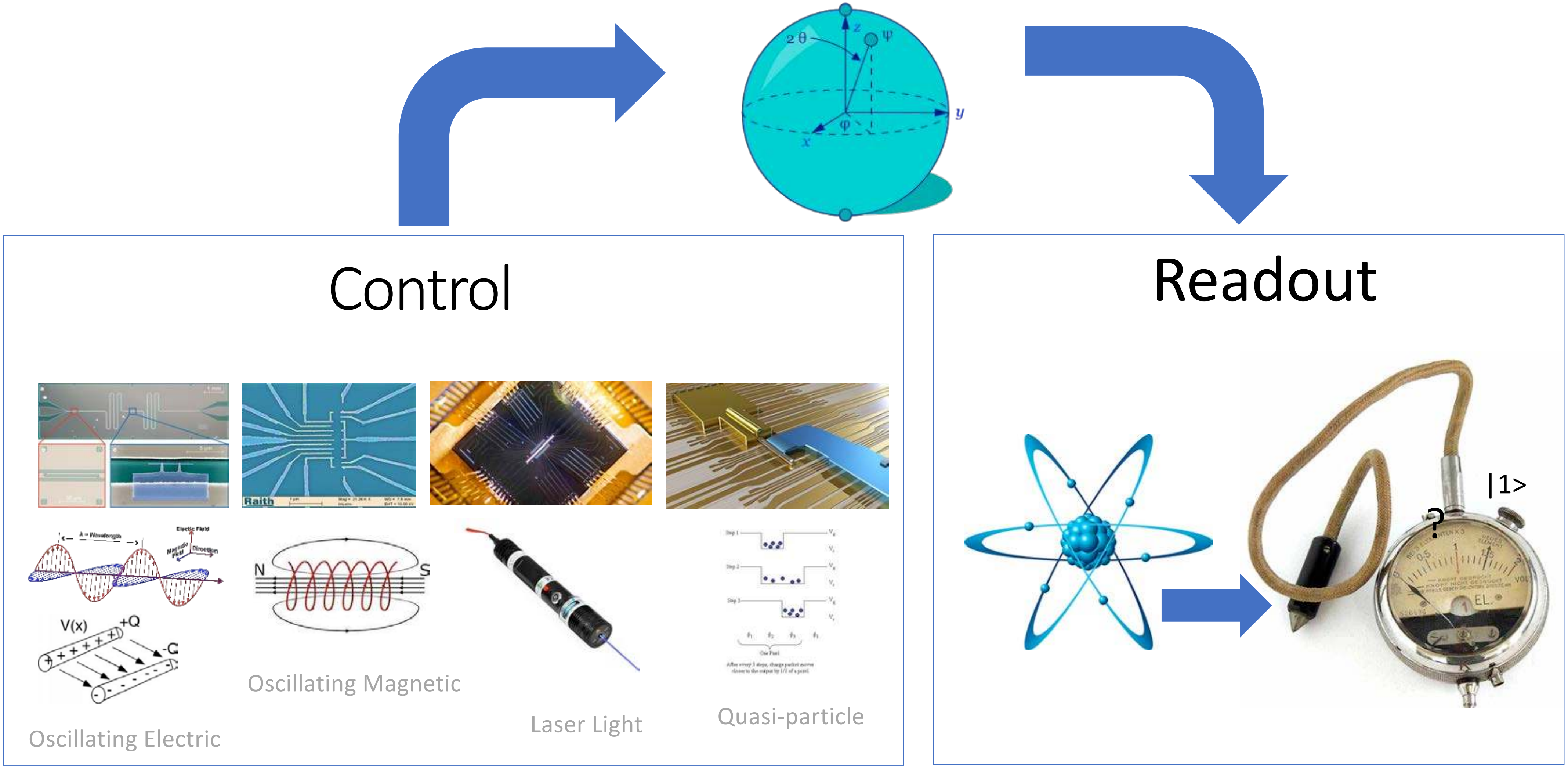
Topological Qubits



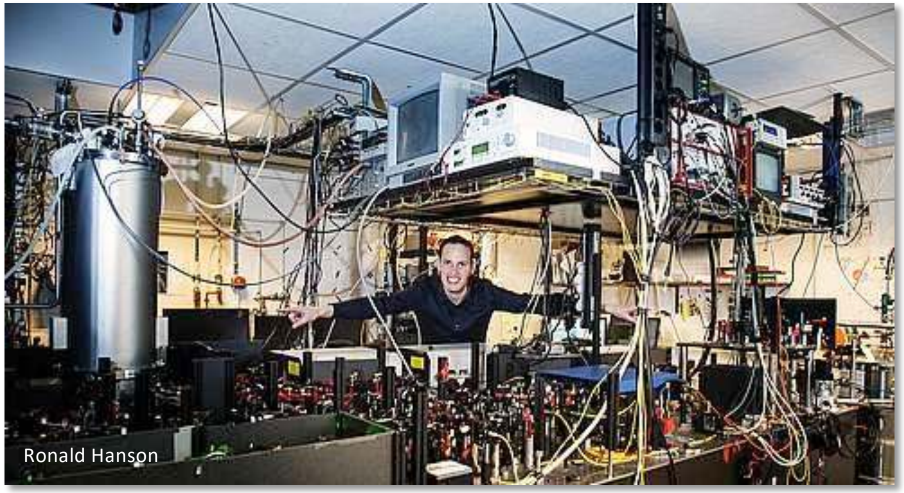
Spin Qubits

- Control via microwave pulses.
- Readout via detection of amplitude / phase of microwaves.
- Cryogenic operation.

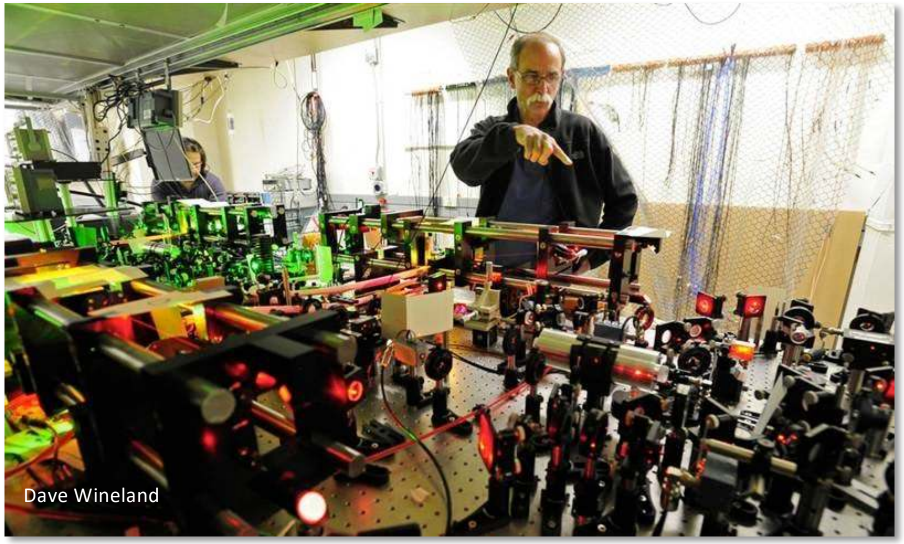
Quantum-Classical Interface



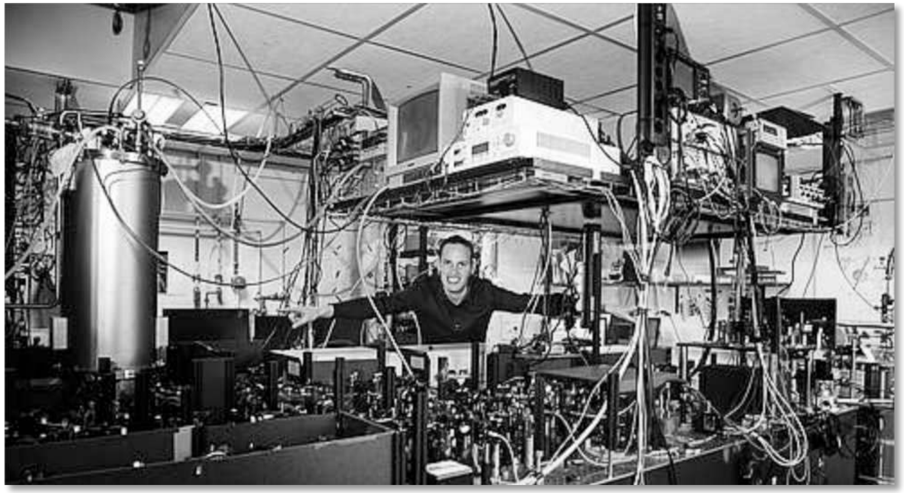
See: *Engineering the Quantum-Classical Interface of Solid-State Qubits* DJR, Nature Quantum Information, 1, (2015).

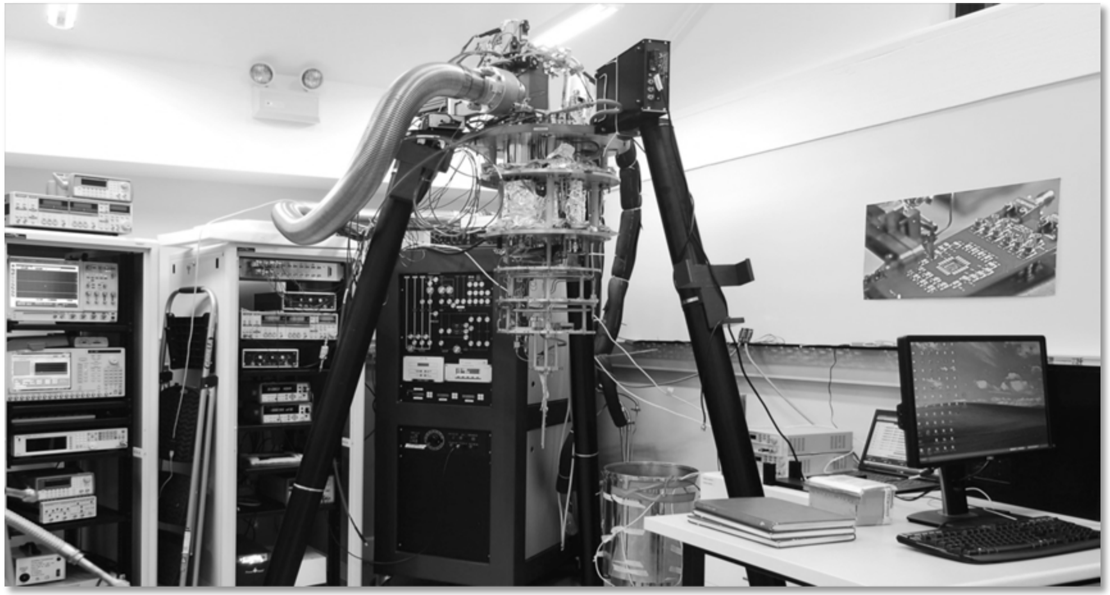


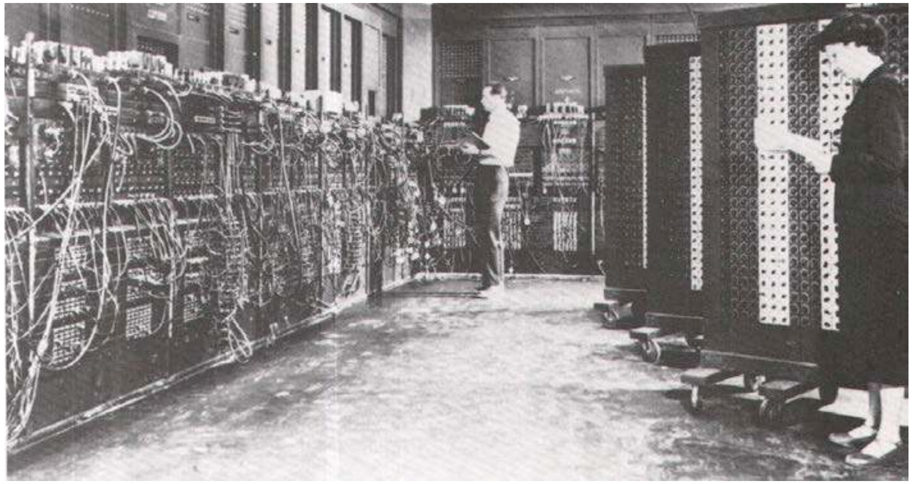
Ronald Hanson

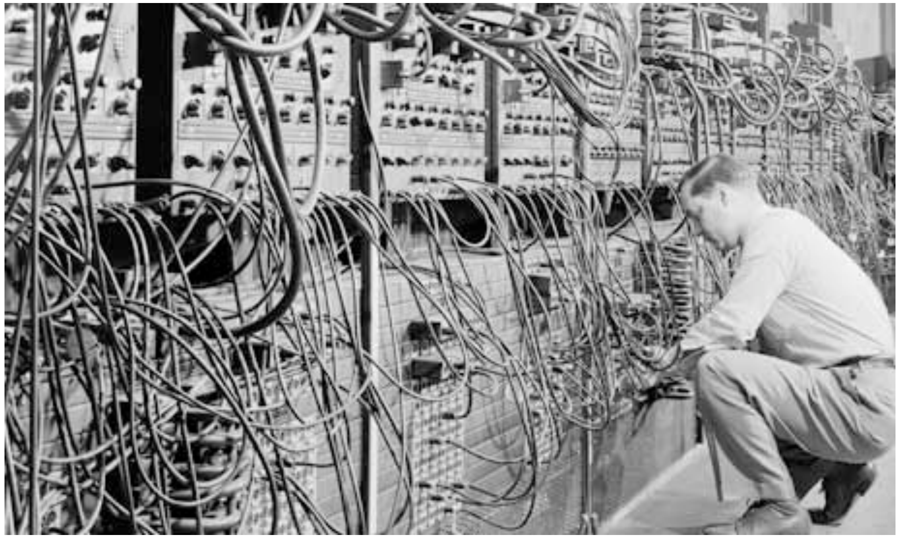


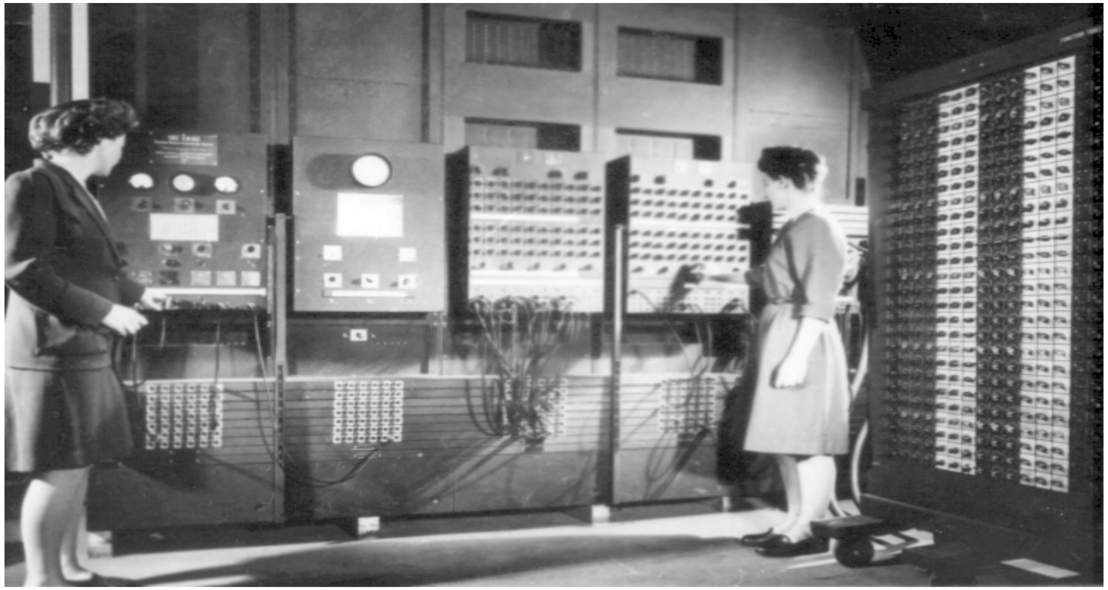
Dave Wineland





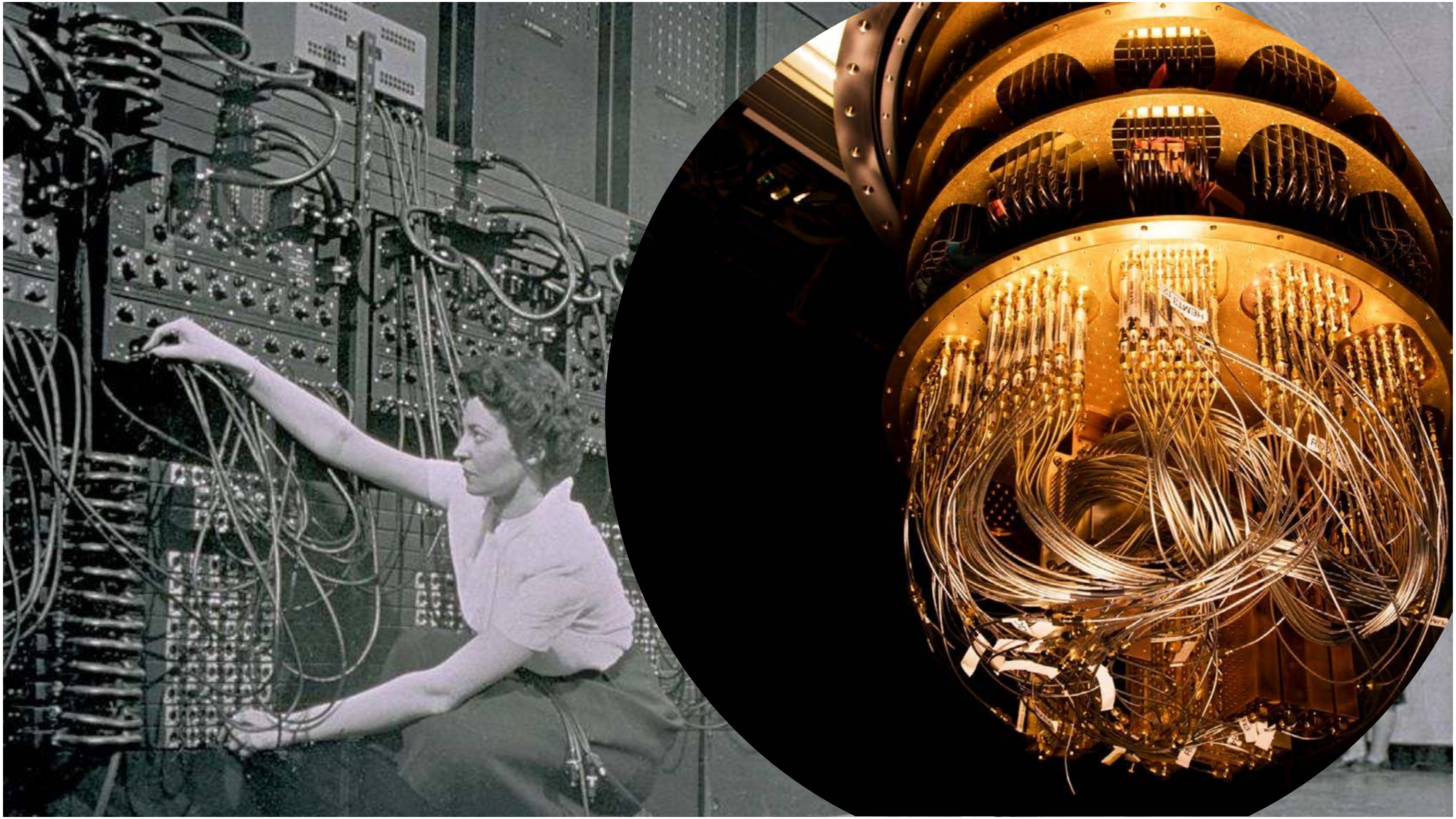






However, all these functions suffer from what has been called 'the tyranny of numbers.' Such systems, because of their complex digital nature, require hundreds, thousands, and sometimes tens of thousands of electron devices.

— Jack Morton, VP Bell Labs (June 1958).

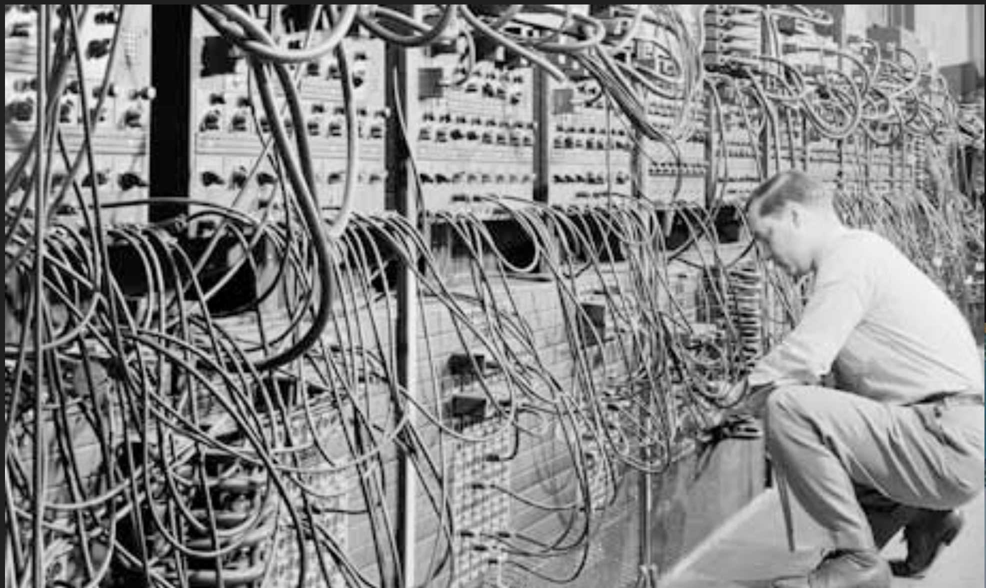


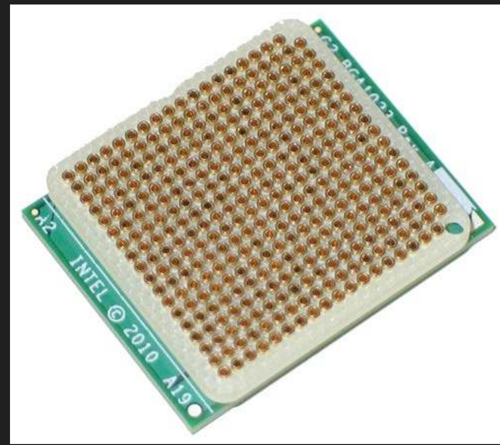
Brute force scaling…

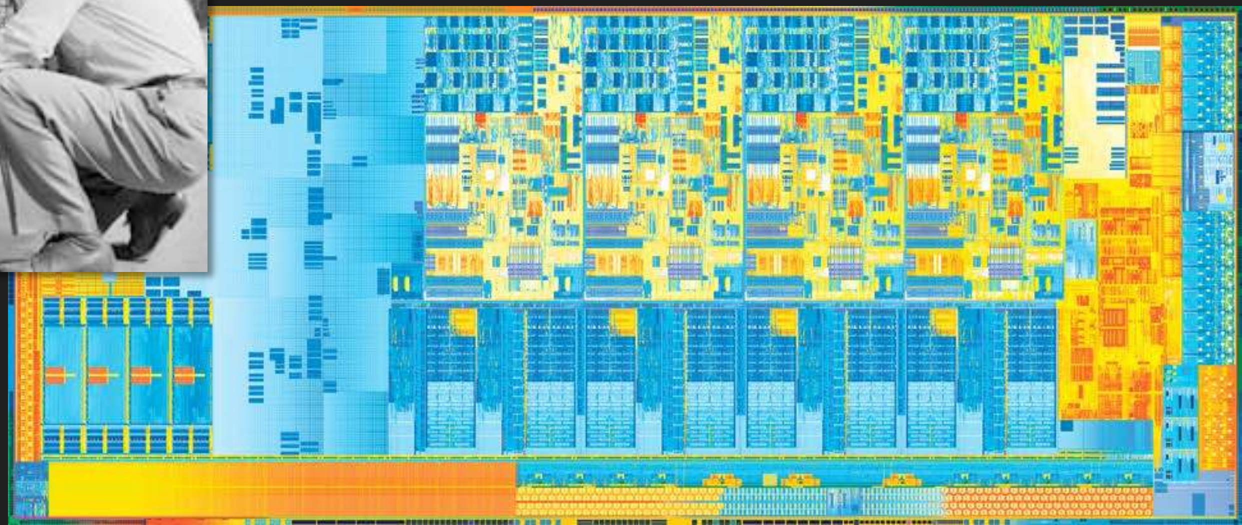
Google’s *Bristlecone 72 Qubits, 2 control lines per qubit… Impressive!*


R6
PUMP5

Integration and Abstraction are Essential

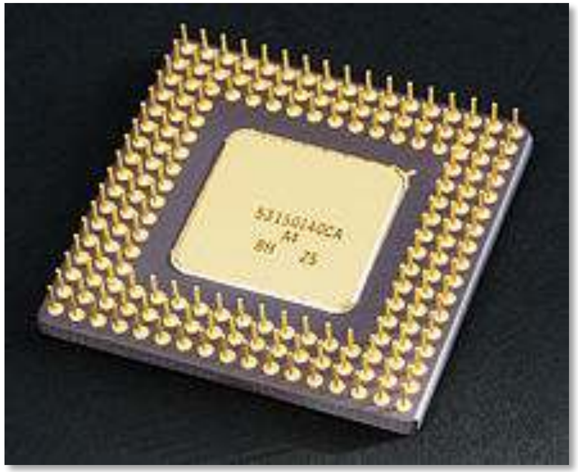


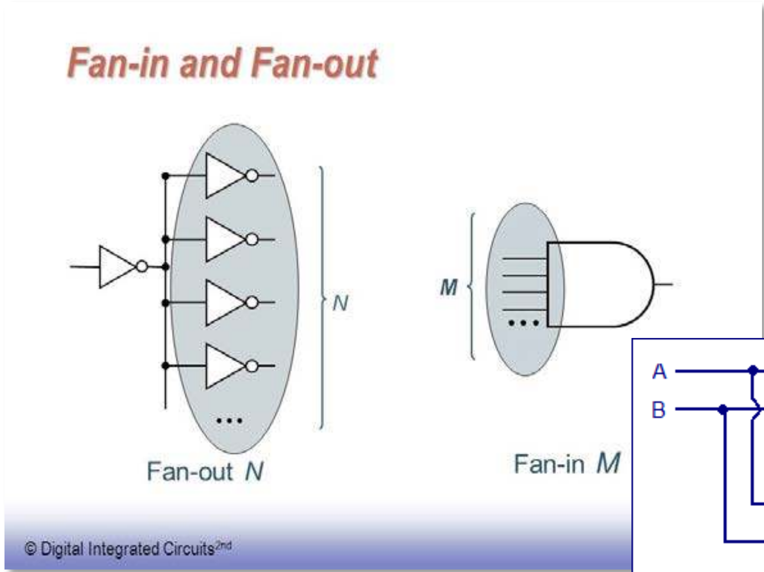


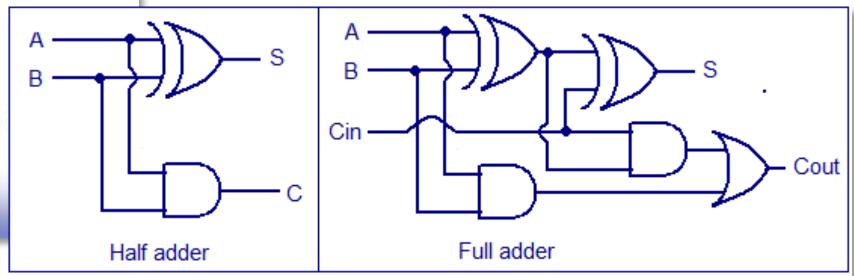


Intel Ivy-Bridge: 2 billion transistors. 340 wires on a BGA

IO Management in Classical VLSI







Rent's Rule: $T = t\, g^{\,a}$

T = number of IOs

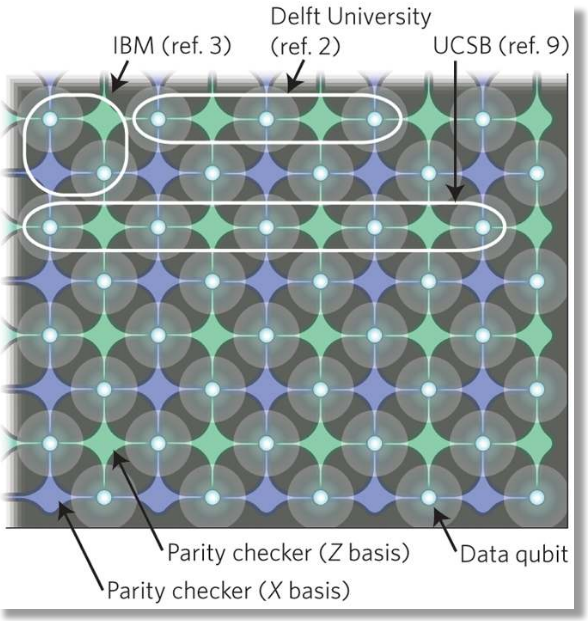
g = number of gates

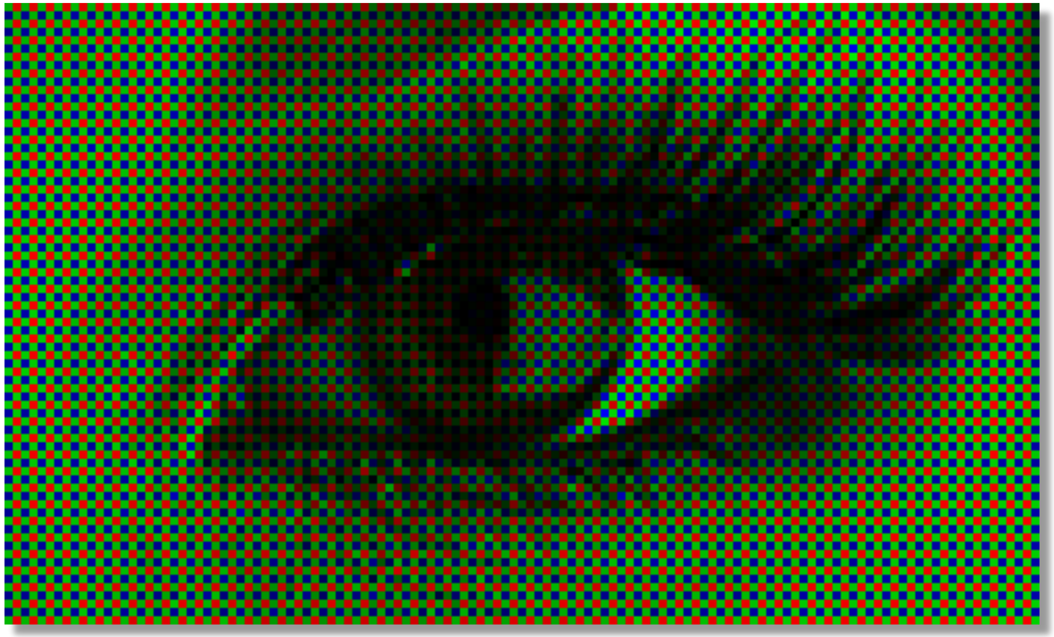
t, a are constants

Fan-out: "Output of one gate feeds the input of another"

Quantum Circuits are Different!

Each qubit requires a unique, independent set of IO channels…

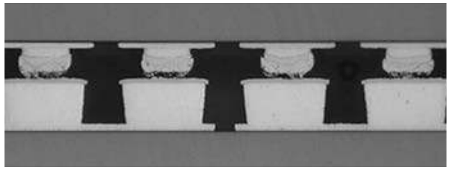




Leads to an IO - Bottleneck at the Quantum-Classical Interface

Challenges at the Quantum-Classical Interface

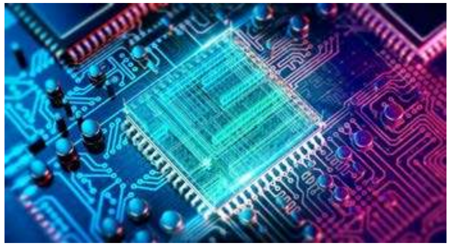
- IO Management



- Footprint / interconnect density

- Heat and Power

- Distributed verse integrated systems
  (synchronicity, latency, wavelength effects..).



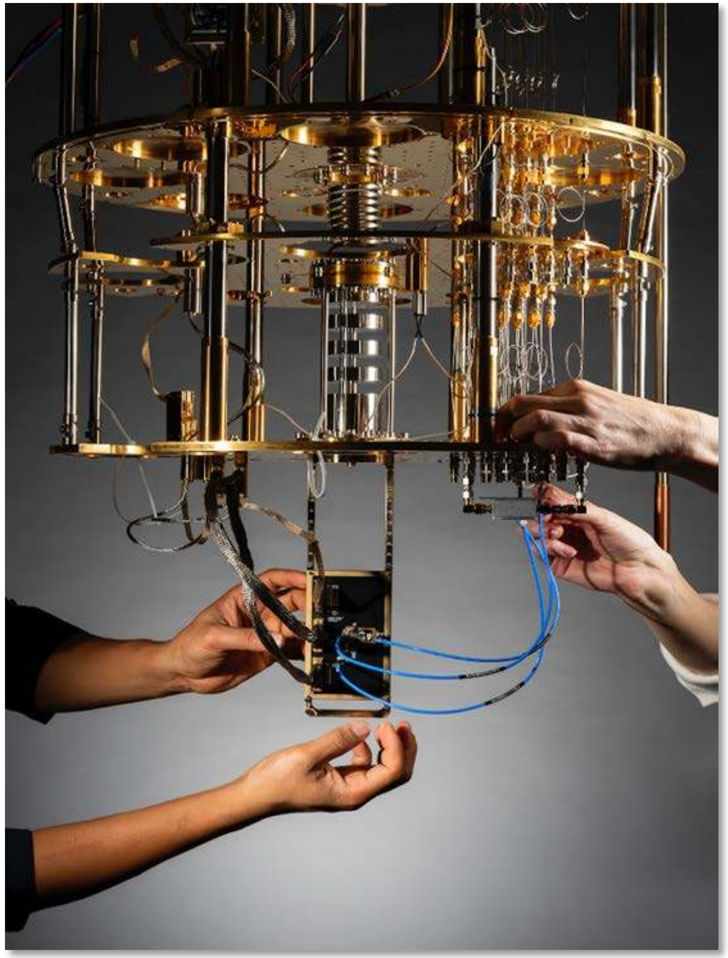
- Noise, crosstalk, interference

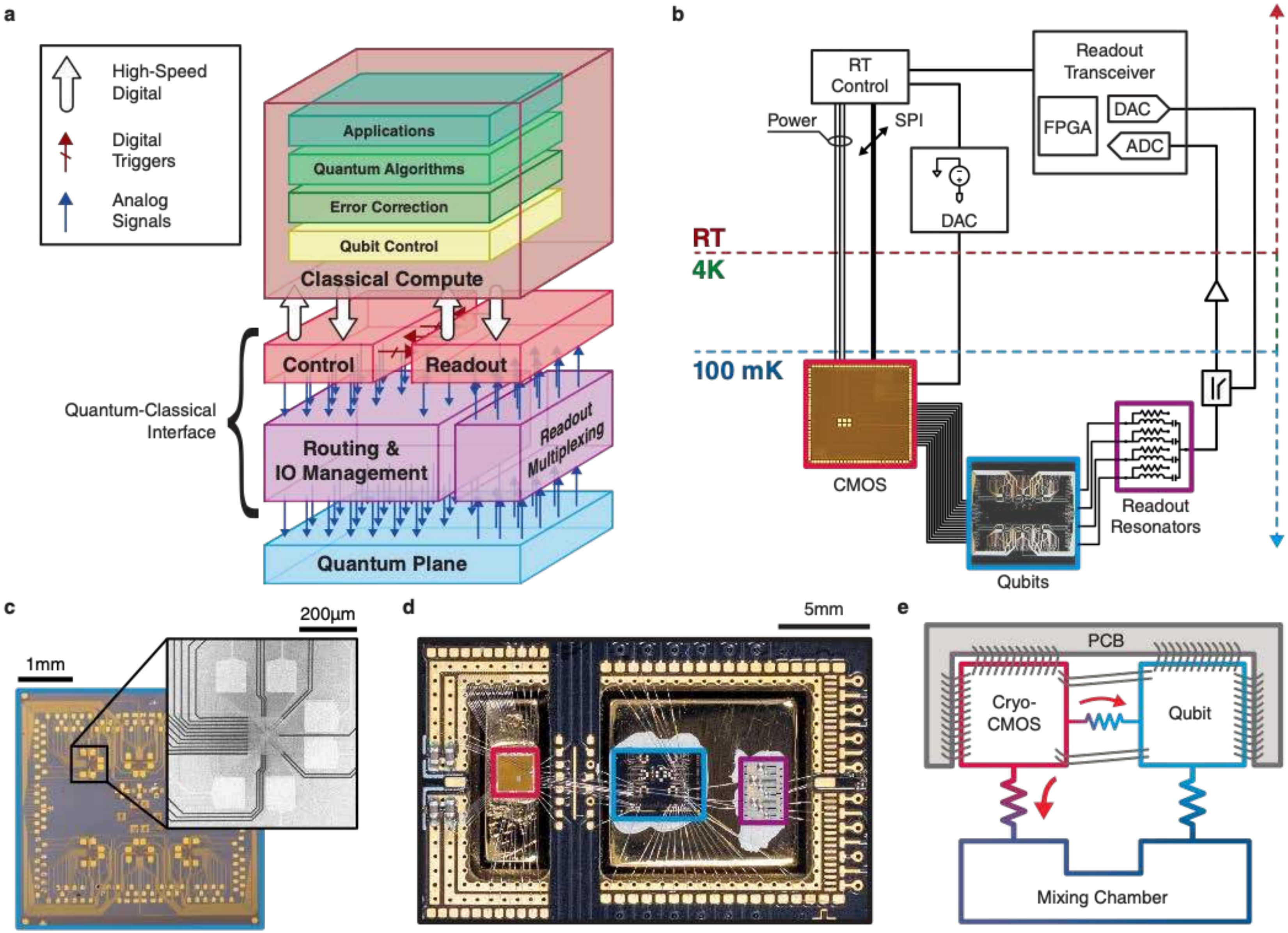
- Bandwidth / rise-time

All aspects can be addressed by moving the interface electronics into the cold

See: *Challenes in Scaling up the Control Interface of a Quantum Computer,* DJR, arXiv:2965871 (2019).

100,000 transistors, operating at 100 mK




a
High-Speed Digital
Digital Triggers
Analog Signals
Applications
Quantum Algorithms
Error Correction
Qubit Control
Classical Compute
Control
Readout
Quantum-Classical Interface
Routing & IO Management
Readout Multiplexing
Quantum Plane
b
RT Control
Power
SPI
DAC
Readout Transceiver
FPGA
DAC
ADC
RT
4K
100 mK
CMOS
Qubits
Readout Resonators
c
1mm
200µm
d
5mm
e
PCB
Cryo-CMOS
Qubit
Mixing Chamber

APPLIED PHYSICS LETTERS **104**, 103108 (2014)

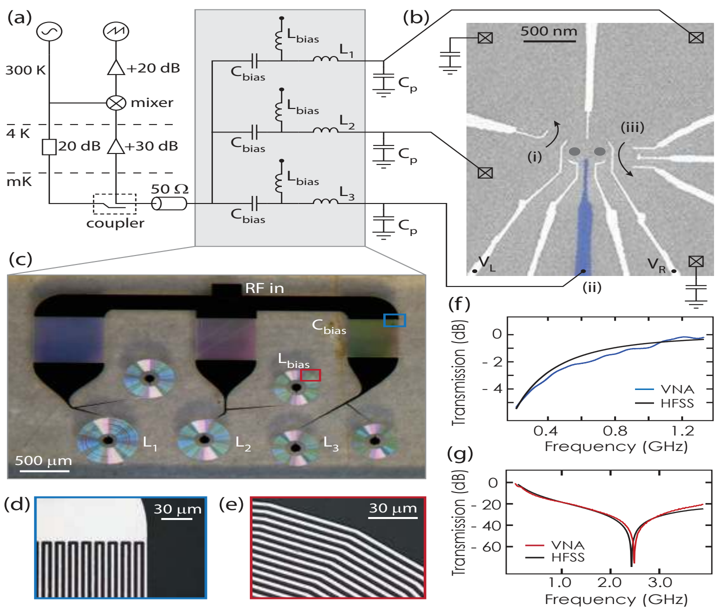
Frequency multiplexing for readout of spin qubits

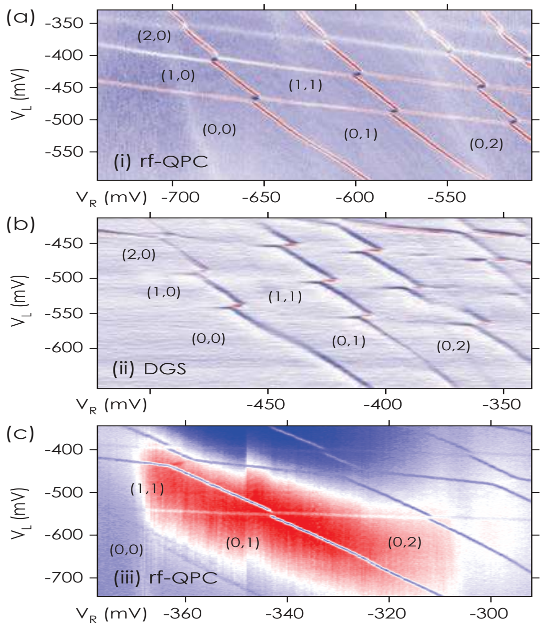
J. M. Hornibrook,[1] J. I. Colless,[1] A. C. Mahoney,[1] X. G. Croot,[1] S. Blanvillain,[1] H. Lu,[2] A. C. Gossard,[2] and D. J. Reilly[1,a)]

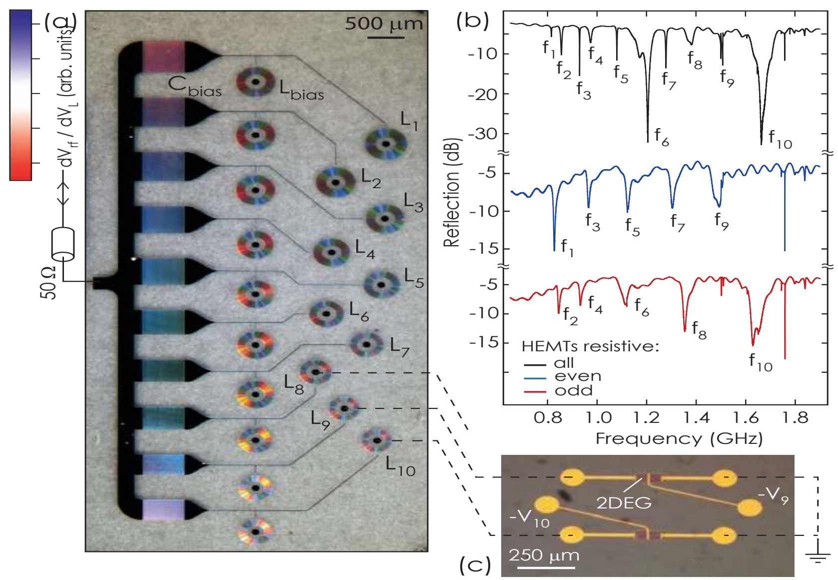
[1]*ARC Centre of Excellence for Engineered Quantum Systems, School of Physics, University of Sydney, Sydney, NSW 2006, Australia*

[2]*Materials Department, University of California, Santa Barbara, California 93106, USA*

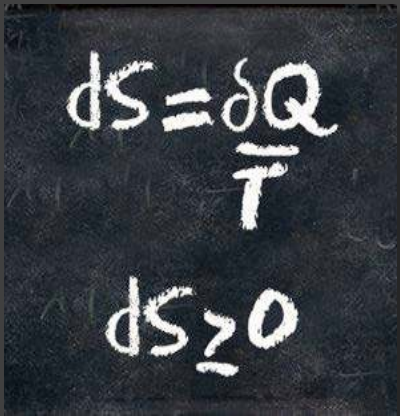
(Received 24 December 2013; accepted 26 February 2014; published online 12 March 2014)

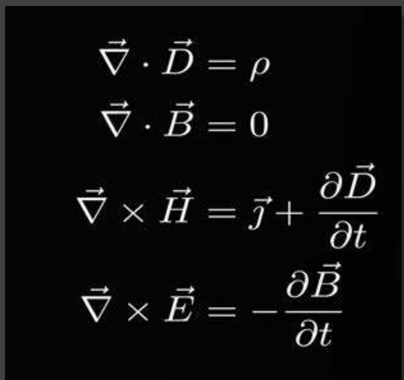






New physics leads to new technologies

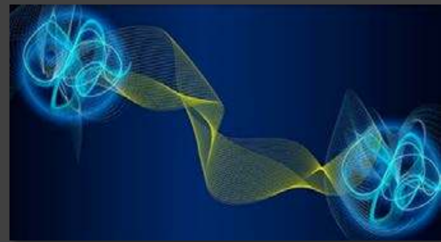


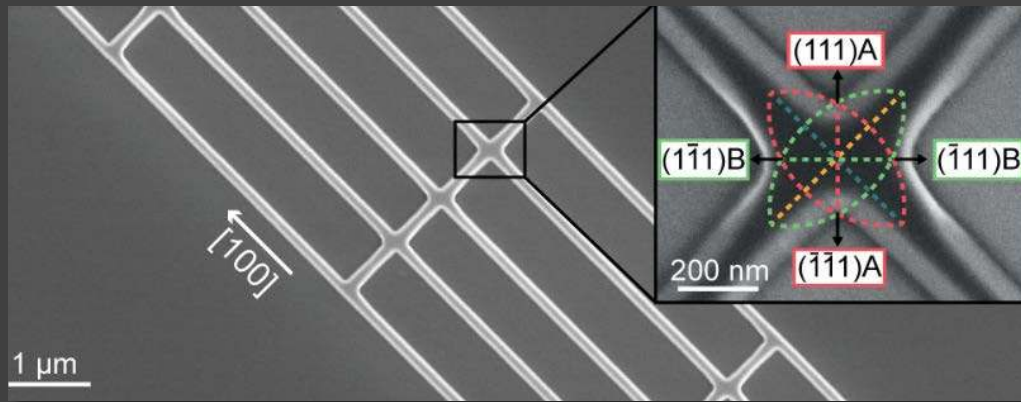


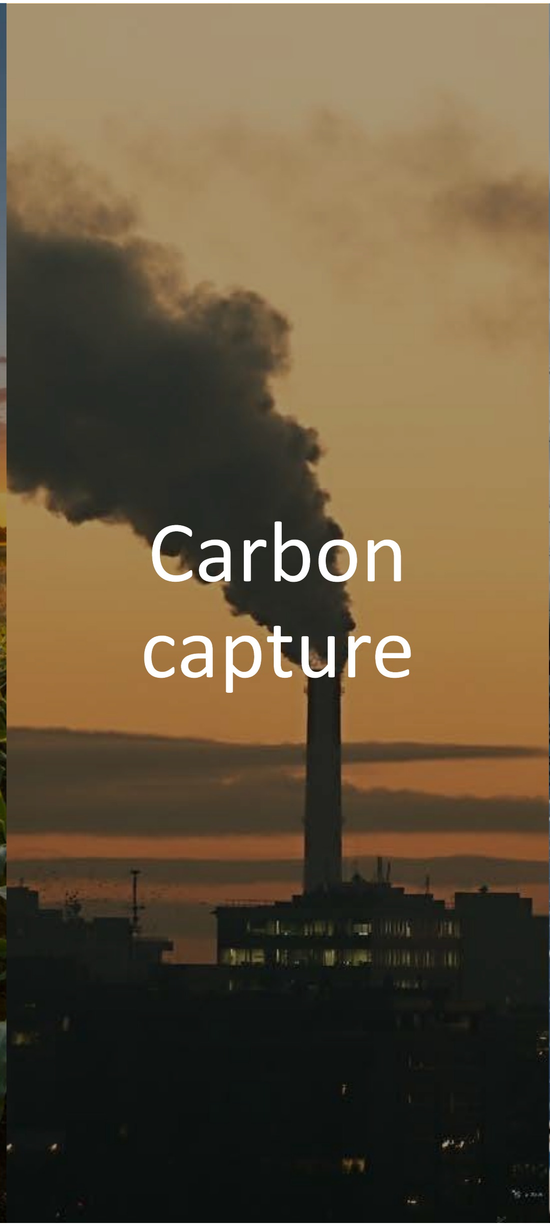
Superposition

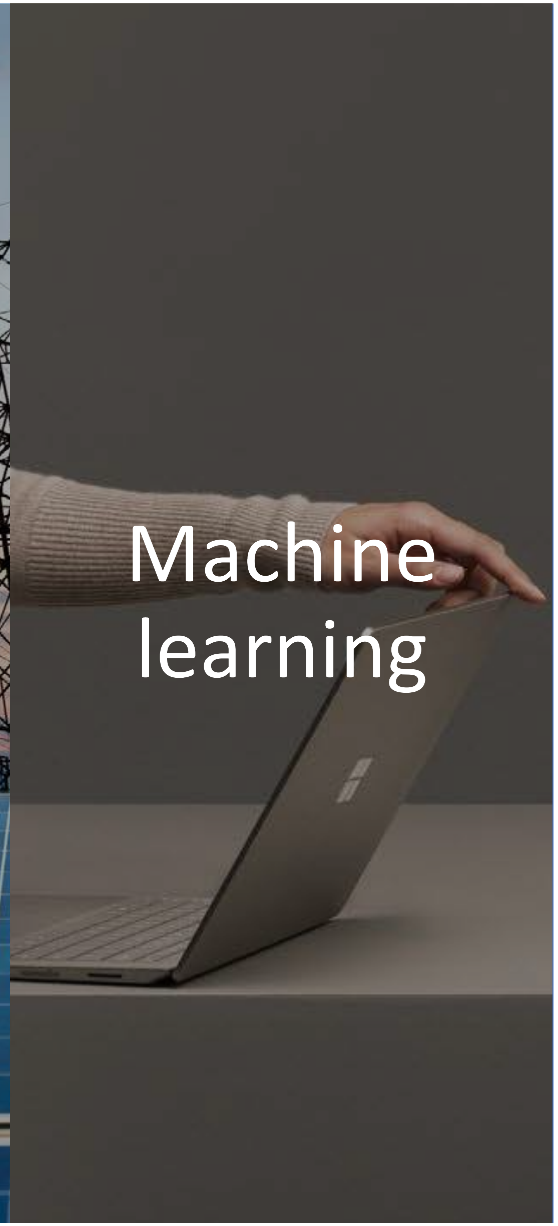
Quantum Measurement

Entanglement

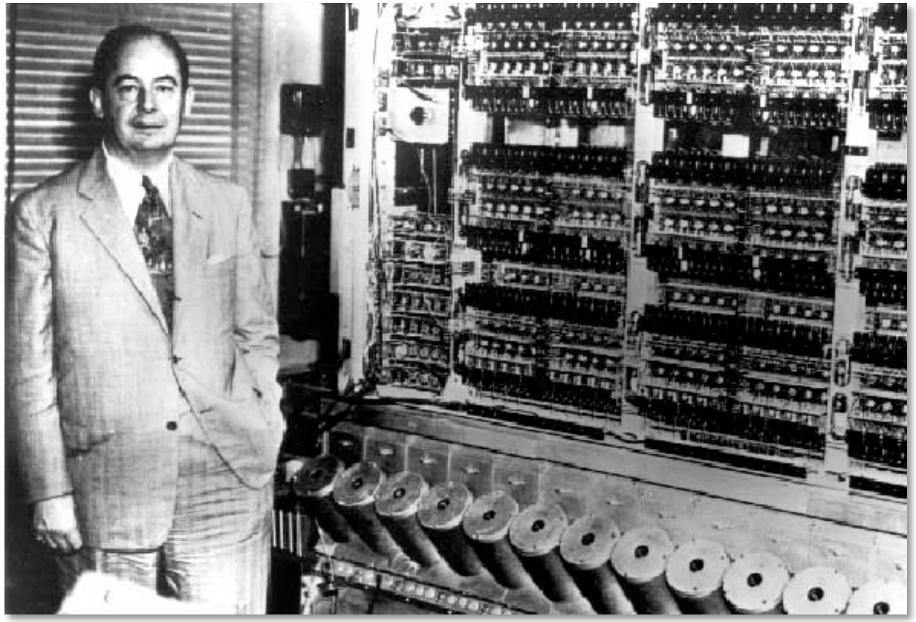





Nitrogen fixation

Carbon capture

Materials science

Machine learning

Taming the complexity: John von Neumann



“The projected device, or rather the species of devices of which it is to be the first representative, is so radially new that many of its uses will become clear only after it has been put into operation,”

“These uses which are not, or not easily, predictable now, are likely to be the most important ones. Indeed they are by definition those which we do not recognize at present because they are farthest removed from… our present sphere.”

- John von Neumann to Lewis L. Strauss, 1945.

MICROSOFT.COM/QUANTUM