Applied Physics Seminar

Lunch time, Every Wednesday

APPH E4901: Discussion of specific and self-contained problems in areas such as applied EM, physics of solids, and plasma physics.
Topics change yearly.

APPH E4903: Discussion of specific and self-contained problems in areas such as applied EM, physics of solids, and plasma physics.
Formal presentation of a term paper required.
Topics change yearly.

Rigetti Computing’s lab in Fremont, California.
Source: Rigetti Computing

Quantum Computers Today Aren’t Very Useful. That Could Change

By Eric Newcomer

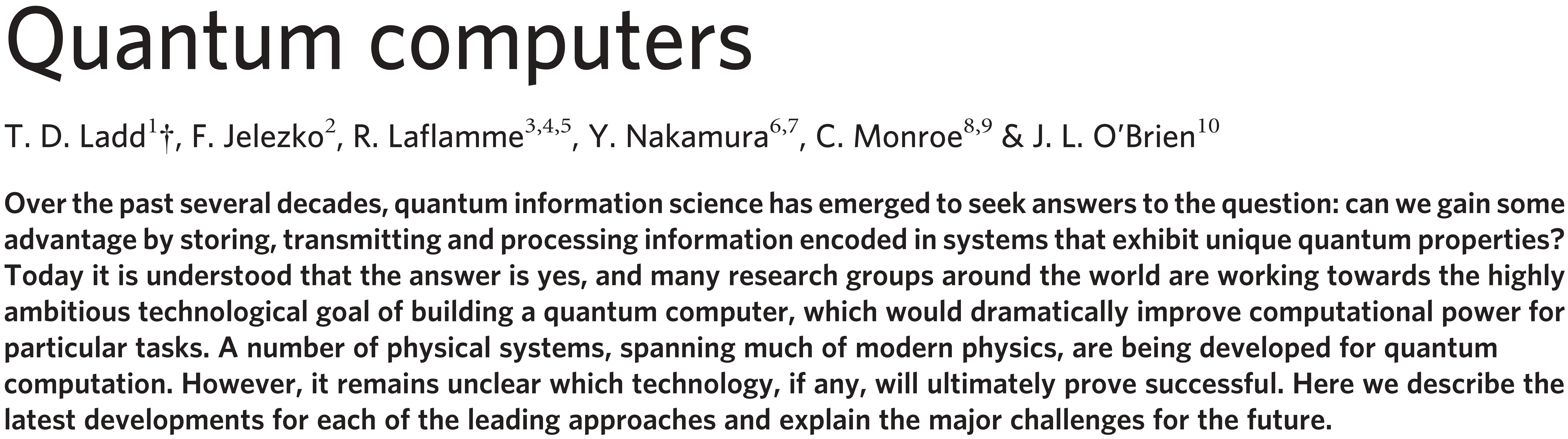
Bloomberg, August 7, 2018

- Few corners of the tech industry are as tantalizing or complex as quantum computing. For years evangelists have promised machines capable of breaking the most impenetrable coded messages, unlocking the secret properties of the physical world and putting supercomputers to shame.

- But Rigetti Computing, one of the most prominent and well-funded startups in the field, would just like to lower everyone’s expectations.

- **Right now, Rigetti’s challenge for itself is this:** ***Can it solve one, single problem with a quantum computer that a conventional machine cannot?*** Even if it just meant answering a question more quickly or cheaply than a supercomputer, the team of physicists and mathematicians at the startup’s Berkeley, California, office would be overjoyed.

Nature, **464**, March 2010 (https://www.nature.com/articles/nature08812)



Quantum computers

T. D. Ladd[1]†, F. Jelezko[2], R. Laflamme[3,4,5], Y. Nakamura[6,7], C. Monroe[8,9] & J. L. O’Brien[10]

Over the past several decades, quantum information science has emerged to seek answers to the question: can we gain some advantage by storing, transmitting and processing information encoded in systems that exhibit unique quantum properties? Today it is understood that the answer is yes, and many research groups around the world are working towards the highly ambitious technological goal of building a quantum computer, which would dramatically improve computational power for particular tasks. A number of physical systems, spanning much of modern physics, are being developed for quantum computation. However, it remains unclear which technology, if any, will ultimately prove successful. Here we describe the latest developments for each of the leading approaches and explain the major challenges for the future.

“A large-scale quantum computer is certainly **an extremely ambitious goal,** appearing to us now as large, fully programmable classical computers must have seemed a century ago. However, … when we have mastered quantum technology enough to scale up a quantum computer, **we will have tamed the quantum world** and become inured to a new form of technological reality.”

Requirements for a Quantum Computer

- **The ‘closed box’ requirement:** a quantum computer’s internal operation must otherwise be isolated from the rest of the Universe. Small amounts of information leakage from the box can disturb the fragile quantum mechanical waves, causing the quantum mechanically destructive process known as decoherence.

- **Scalability.** The computer must operate in a Hilbert space whose dimensions can grow exponentially without an exponential cost in resources (such as time, space or energy).

- **Universal logic.** The large Hilbert space must be accessible using a finite set of control operations; the resources for this set must also not grow exponentially.

- **Correctability.** It must be possible to extract the entropy of the com- puter to maintain the computer’s quantum state.

Decoherence

Dephasing

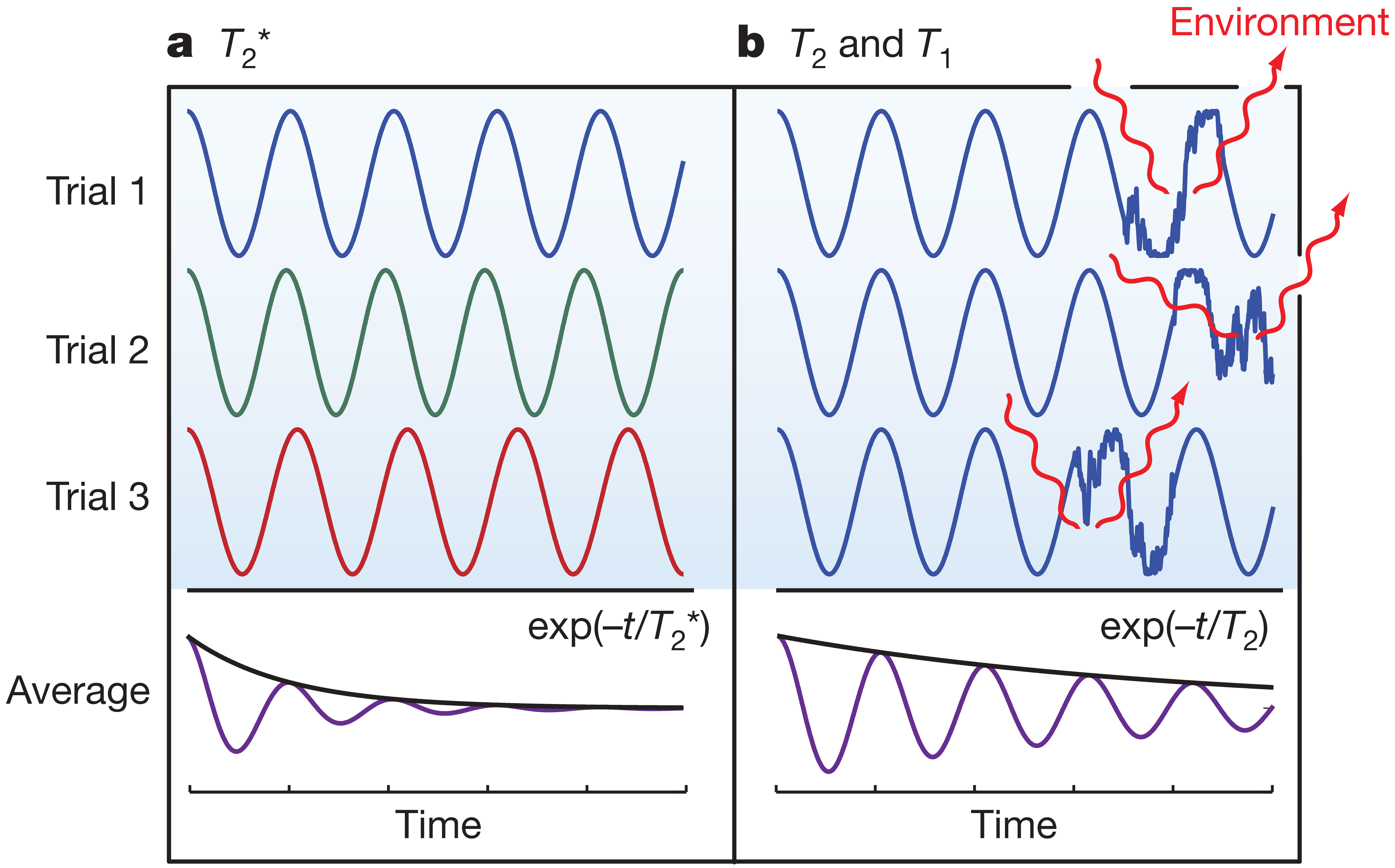


Figure 1 | Dephasing and decoherence. a, An oscillator with frequency varying by trial, as indicated by the differently coloured waves, averages to an oscillation decaying with apparent dephasing timescale T_2^*. **b**, A quantum oscillator interacting with the environment may have phase-kicks in a single trial; these are the processes that harm coherence in quantum computation, and lead to an average decay process of timescale T_2. Equilibration processes are similar, and cause decay on the timescale $T_1 \geq T_2/2$.

Decoherence

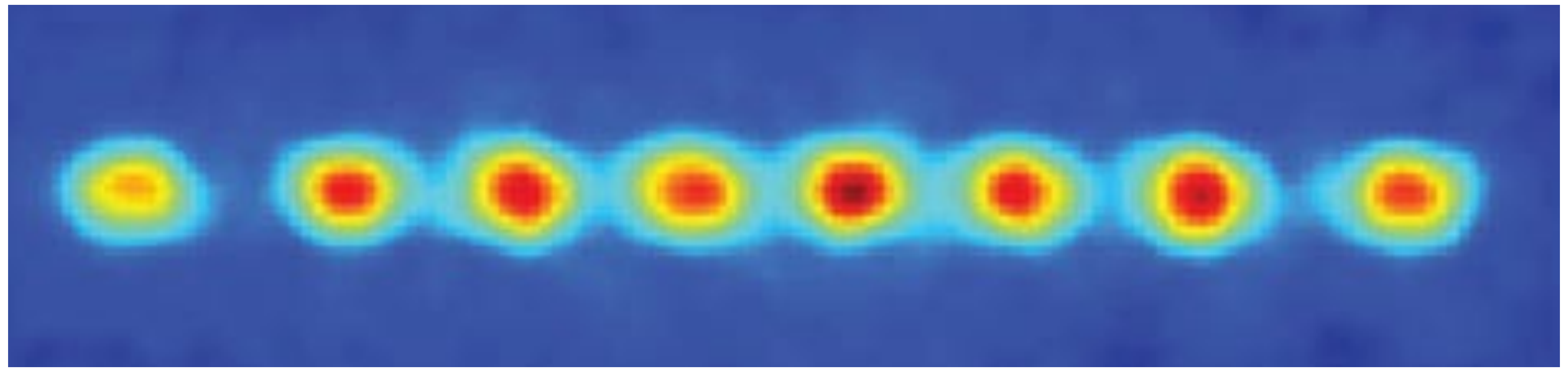
Table 1 | Current performance of various qubits

Type of qubit	T_2	Benchmarking (%)		References
		One qubit	Two qubits	
Infrared photon	0.1 ms	0.016	1	20
Trapped ion	15 s	0.48†	0.7*	104–106
Trapped neutral atom	3 s	5		107
Liquid molecule nuclear spins	2 s	0.01†	0.47†	108
e^- spin in GaAs quantum dot	3 µs	5		43, 57
e^- spins bound to ^{31}P:^{28}Si	0.6 s	5		49
^{29}Si nuclear spins in ^{28}Si	25 s	5		50
NV centre in diamond	2 ms	2	5	60, 61, 65
Superconducting circuit	4 µs	0.7†	10*	73, 79, 81, 109

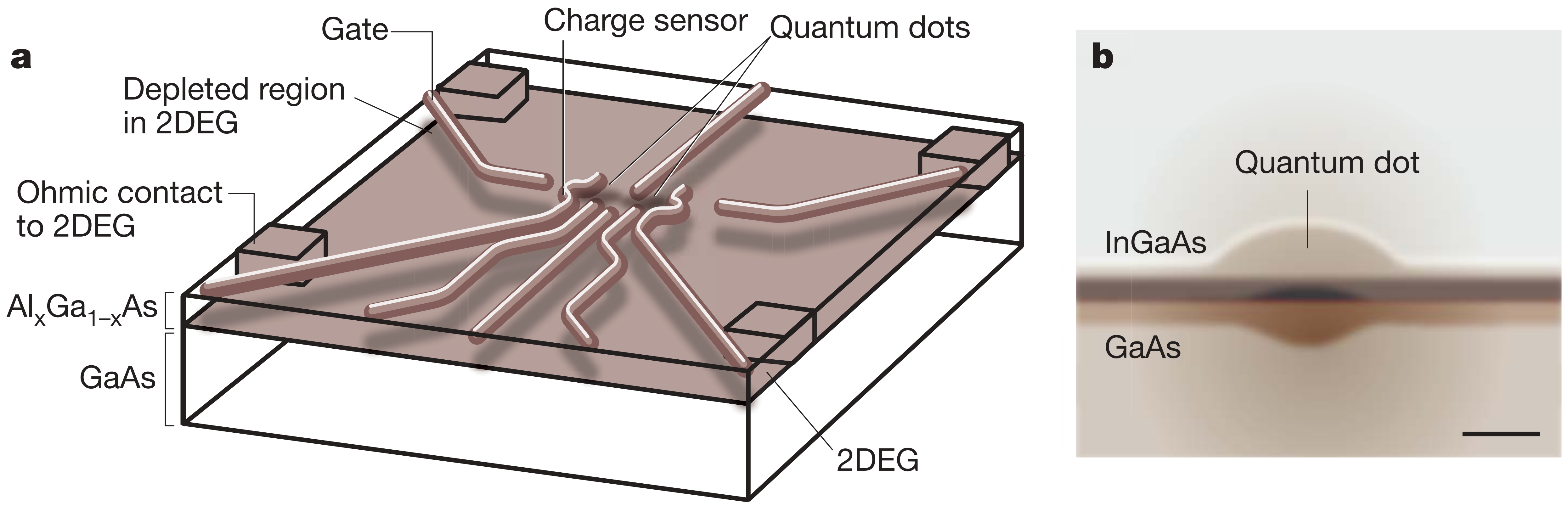
Measured T_2 times are shown, except for photons where T_2 is replaced by twice the hold-time (comparable to T_1) of a telecommunication-wavelength photon in fibre. Benchmarking values show approximate error rates for single or multi-qubit gates. Values marked with asterisks are found by quantum process or state tomography, and give the departure of the fidelity from 100%. Values marked with daggers are found with randomized benchmarking[110]. Other values are rough experimental gate error estimates. In the case of photons, two-qubit gates fail frequently but success is heralded; error rates shown are conditional on a heralded success. NV, nitrogen vacancy.

Some Types of Qubits

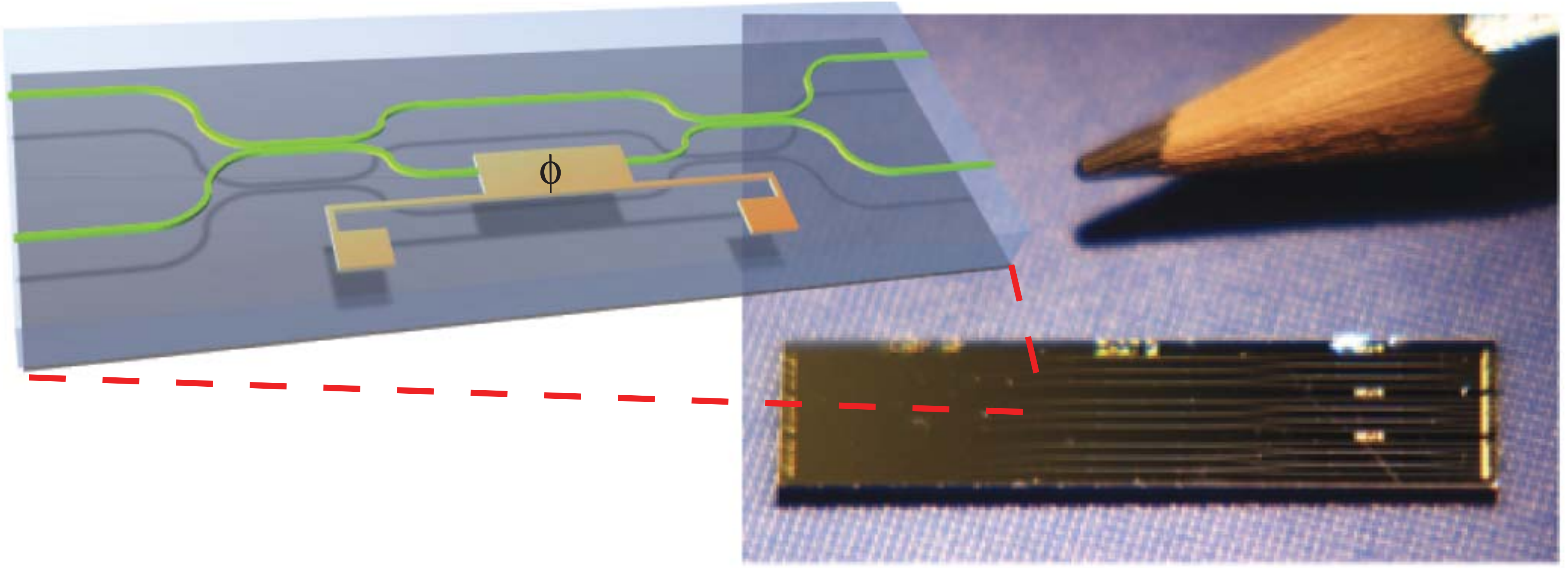
(a) Trapped Ions: "ion highway"



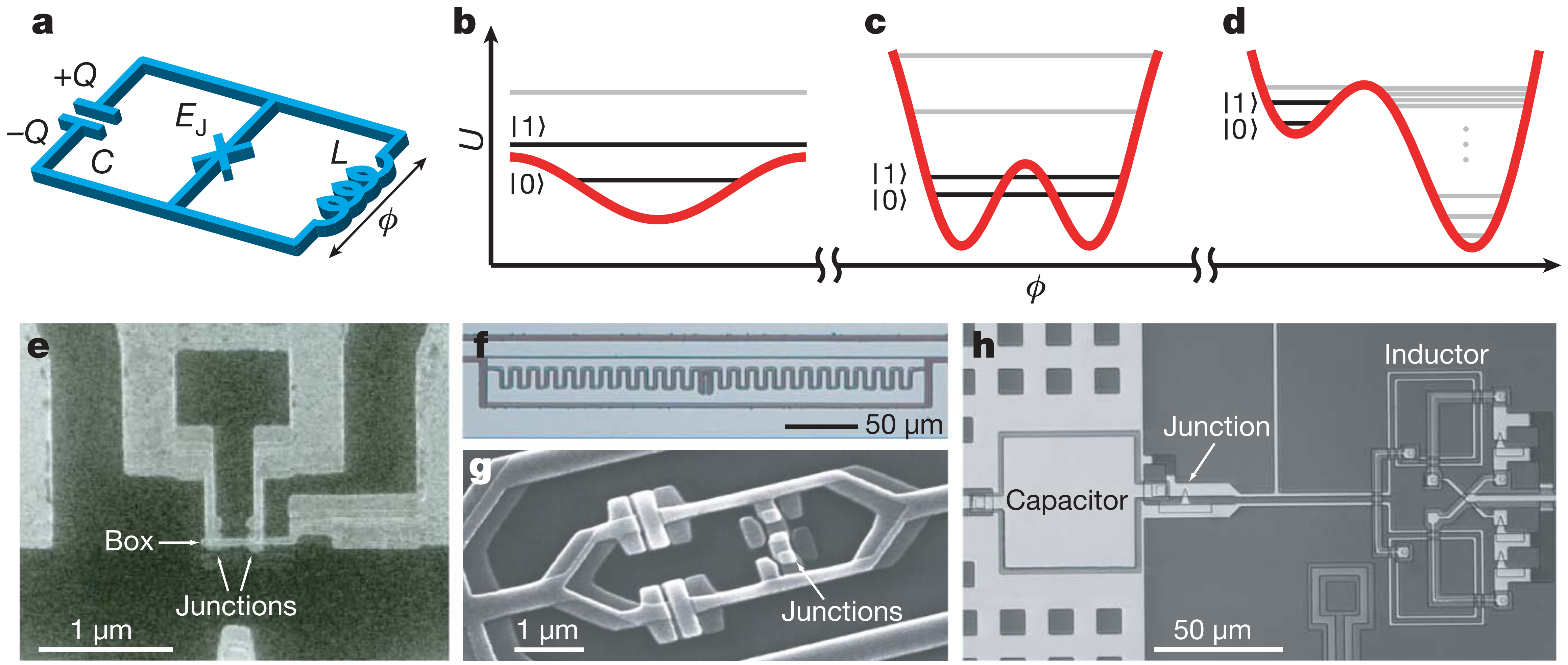
(c) Quantum Dots



(b) Photons

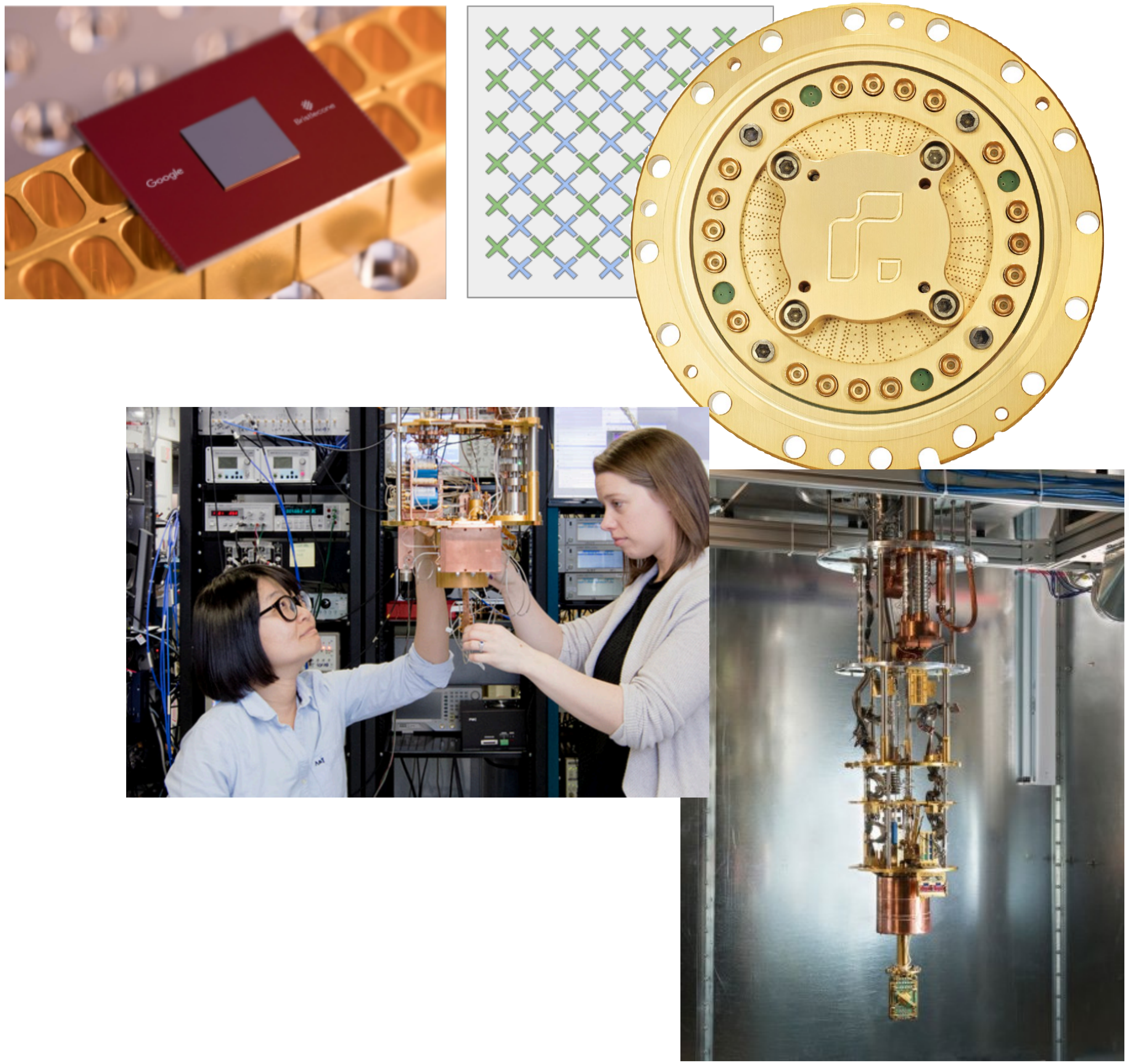


(d) Superconducting Josephson Junctions



Commercial Quantum Computing

- Google: https://ai.google/research/teams/applied-science/quantum-ai/
- Regetti: https://www.rigetti.com
- IBM: https://www.research.ibm.com/ibm-q/
- D-Wave: https://www.dwavesys.com/home



Research Questions

- What are qubits and how do they work?
- What is required to manipulate qubits, to measure qubits, to initialize qubits, to define a quantum solution?
- What is the basic physics defining quantum mechanical processes?
- What are applications of quantum state control:
  - Measurement of single molecules…
  - Magnetic resonances of single atomic/electron spins
  - LIGO
  - Structural dynamics of single molecules, proteins, …
  - Nanoresonators for sensing and detecting everything small

Research Plan

- **Start at the beginning with ultra-cold trapped ions:** the hyperfine two-state system of trapped Be^+: *Phys Rev Letters,* "Demonstration of a Fundamental Quantum Logic Gate", **75**, 4714 (1995), C. Monroe, Meekhof, King, Itano, Wineland

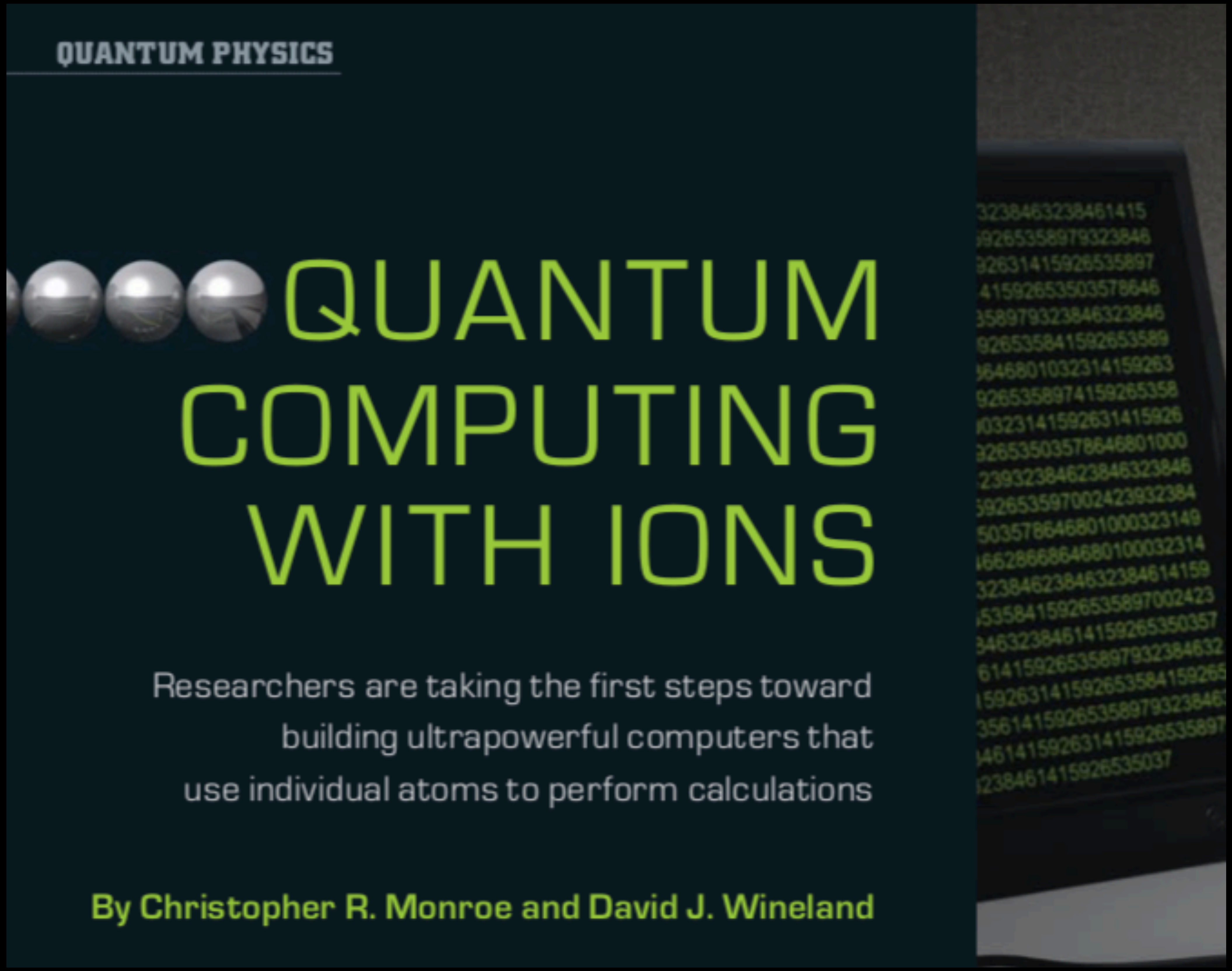
- Nuclear Magnetic Resonance (NMR)

- Superconducting Josephson Junctions, Transmons, …

- *Plus*, some quantum logic along the way…

Assignment for Next Week

- Read Quantum Computing with Ions, *Scientific American (August 2008).*
- Sign up at IBM: https://www.research.ibm.com/ibm-q/



QUANTUM PHYSICS

QUANTUM COMPUTING WITH IONS

Researchers are taking the first steps toward building ultrapowerful computers that use individual atoms to perform calculations

By Christopher R. Monroe and David J. Wineland

Beginners Guide

FAQ for Beginners

Introduction

Getting Started

- Histogram representation (Bar graph)

The Weird and Wonderful World of the Qubit

Single-Qubit Gates

- Creating superposition
- Introducing qubit phase
- Summary of quantum gates

Multi-Qubit Gates

Entanglement

- Bell and GHZ Tests
- Bell and GHZ Tests (Cont.)
- Results from the GHZ test in the Quantum Experience

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