

Physical qubits and error correction

Hardware examples from the original mixed lecture, followed by error-correction development.

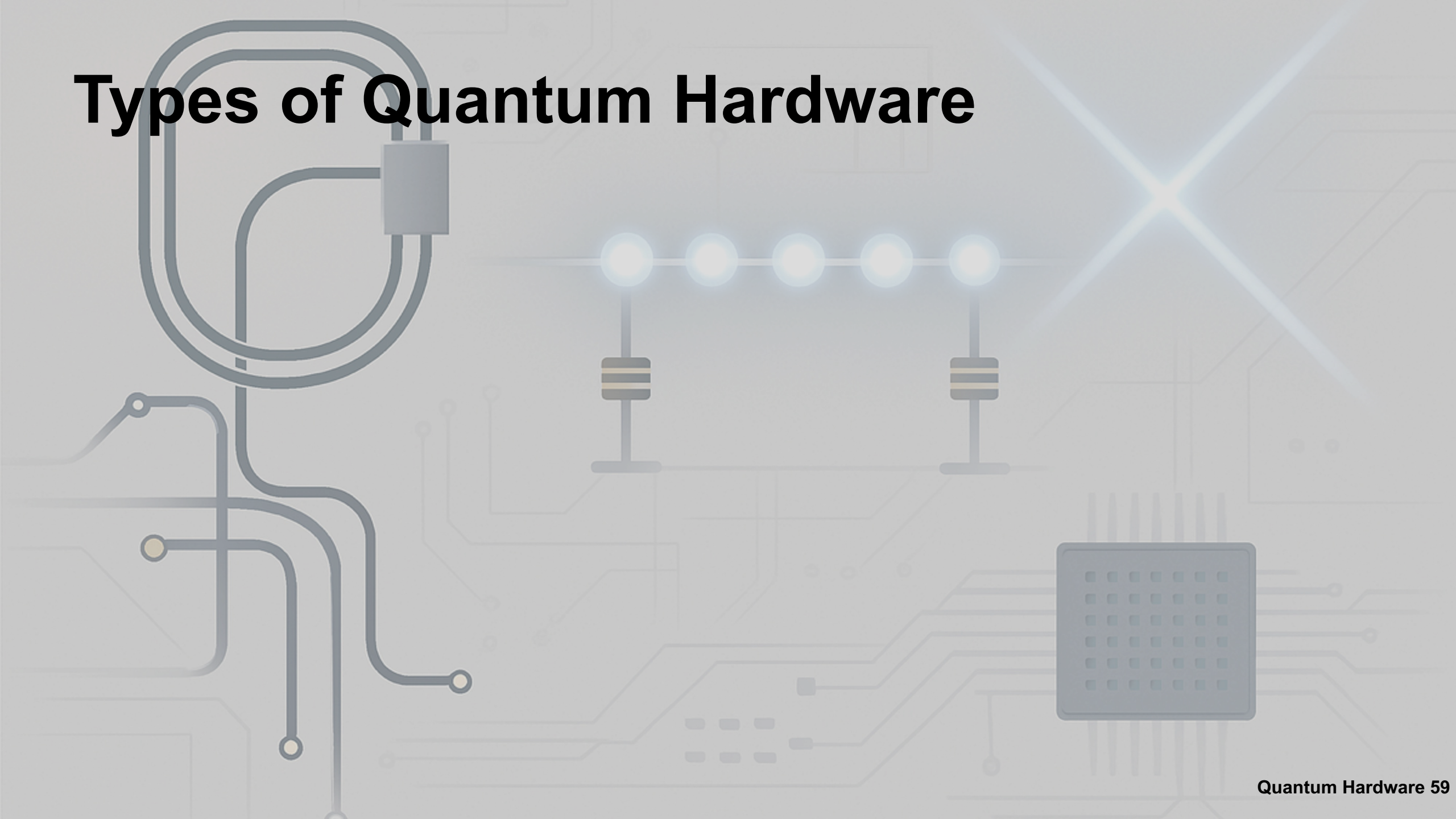
From Theory to Physical Qubits

In 1993 Seth Lloyd described a method for building the first quantum computer.

“Arrays of pulsed, weakly coupled quantum systems ... the basic unit in the array could be a quantum dot, a nuclear spin, ... or any multistate quantum system that interacts locally with its neighbors and can be compelled to switch between states with resonant pulses of light.”

S. Lloyd, A potentially realizable quantum computer, Science, 261(5128): 1569-1571, 1993.

Types of Quantum Hardware



Superconducting Qubits

- **Description:** Utilize superconducting circuits at cryogenic temperatures to perform quantum operations.

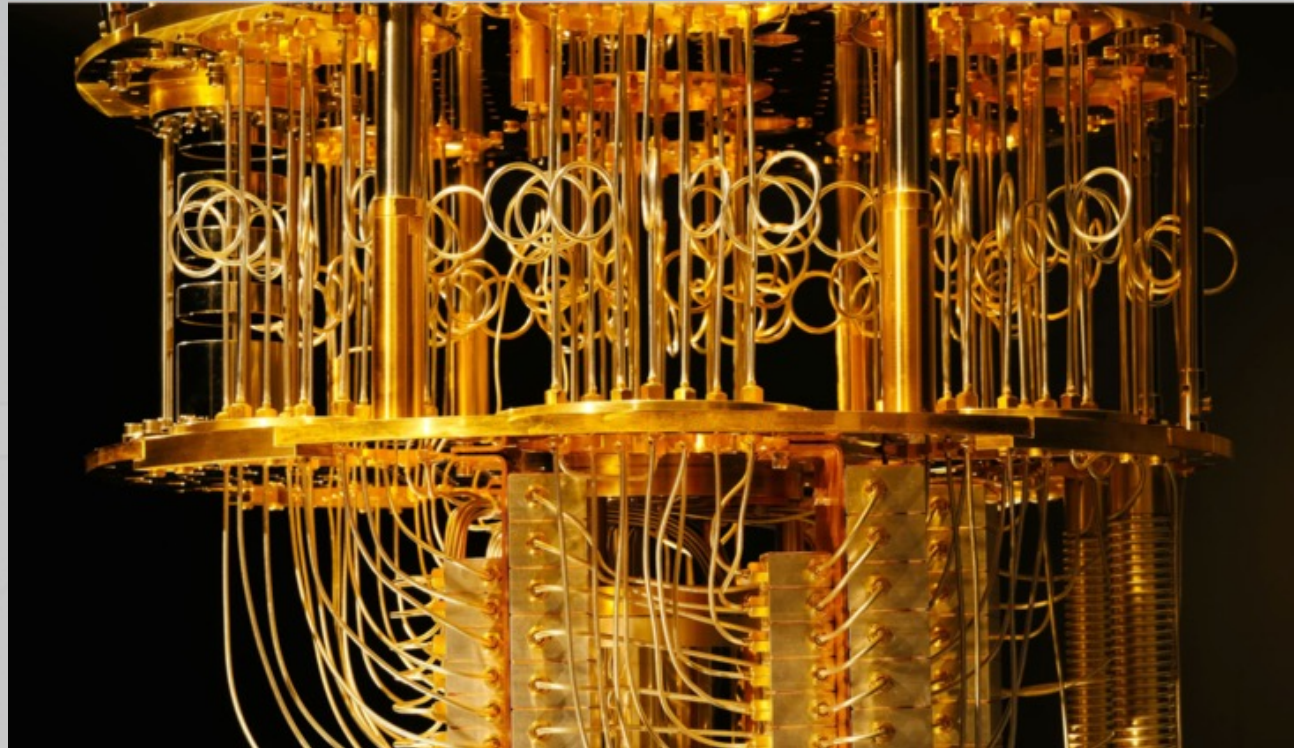
- **Notable Companies:**

- IBM

- Google

- Rigetti Computing

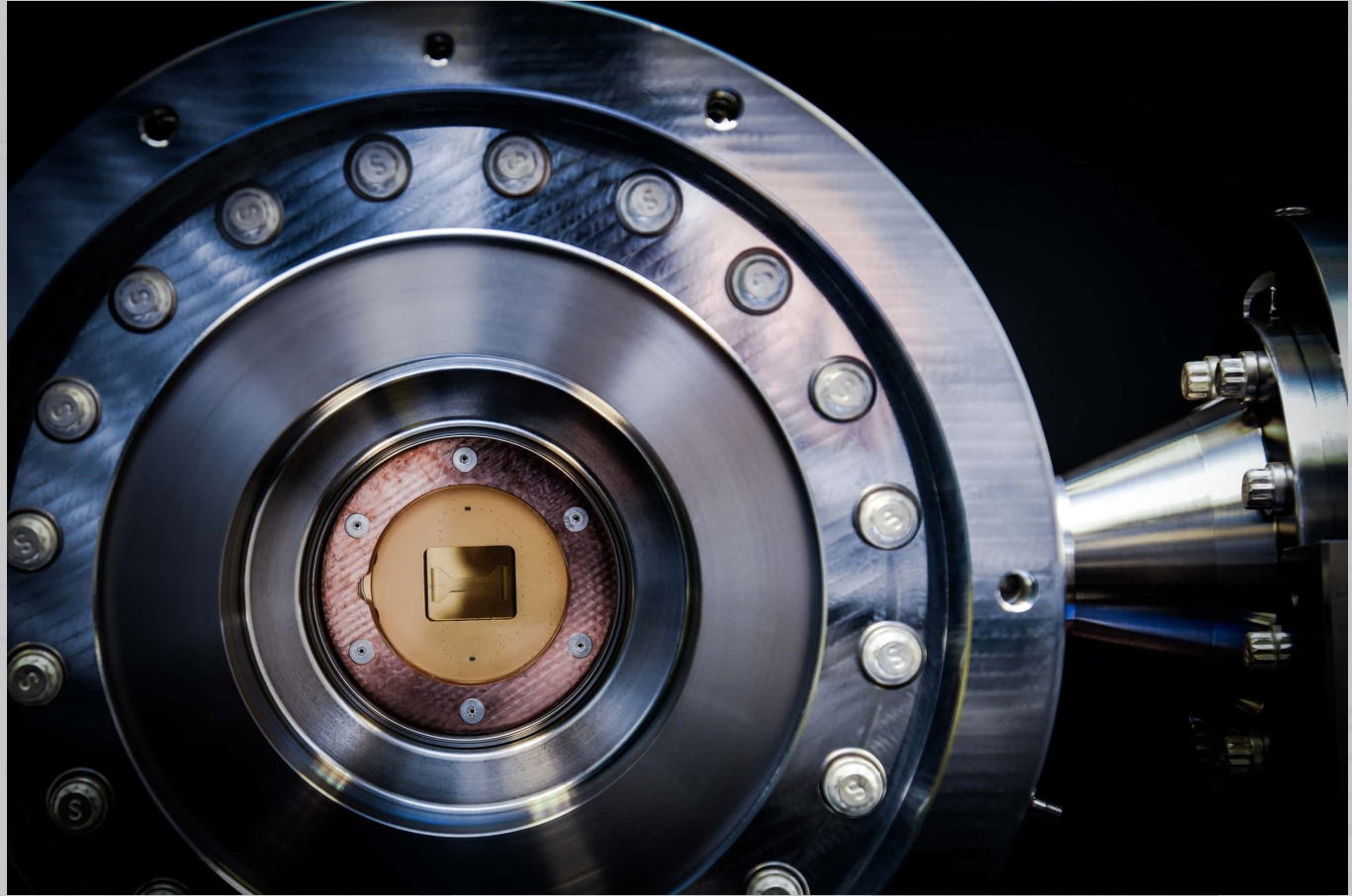
- Intel



Superconducting quantum processor suspended in a cryostat for ultra-cold operation and precise qubit measurement.

Trapped Ion Qubits

- **Description:** Employ ions confined and manipulated using electromagnetic fields.
- **Notable Companies:**
 - IonQ
 - Quantinuum
 - Honeywell

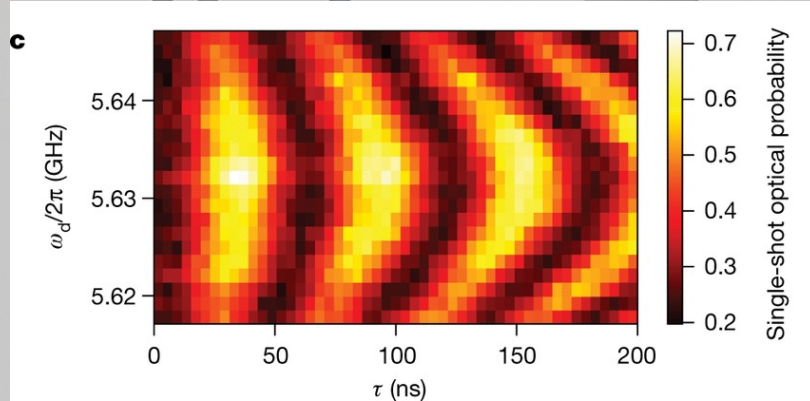


Ion trap quantum processor housed in an ultra-high vacuum chamber, used to isolate and control individual trapped ion qubits.

Measurement in Hardware

Superconducting qubits

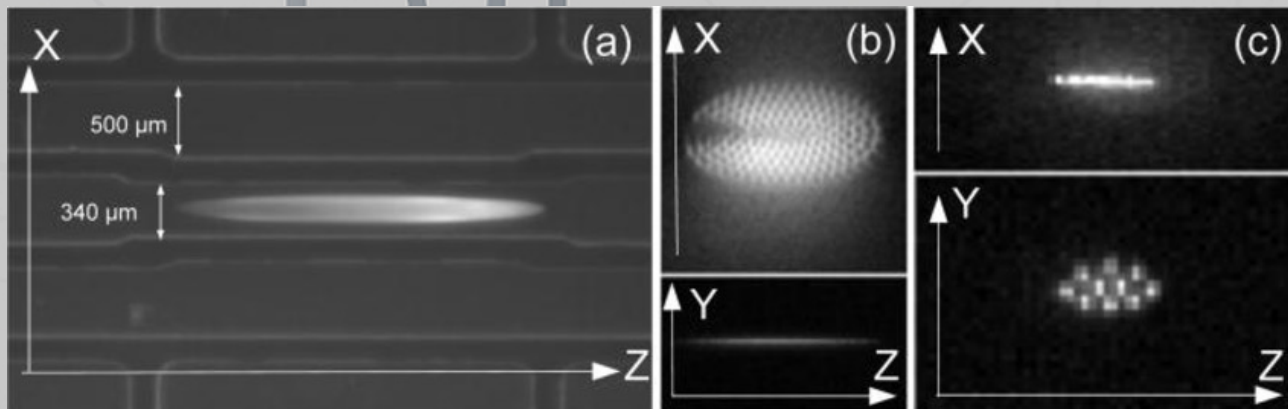
- Readout via resonator frequency shift (microwave cavity QED)



Delaney, R. D., et al. "Superconducting-qubit readout via low-backaction electro-optic transduction." *Nature* 606.7914 (2022): 489-493.

Trapped ions

- Fluorescence detection (ions emit or don't under laser illumination)



Szymanski, B., et al. "Large 2D Coulomb crystals in a radio frequency surface ion trap." *arXiv preprint arXiv:1201.2584* (2012).

Other Quantum Computer Implementation

Photonic Qubits

Use photons for quantum computations, often at room temperature.

- **PsiQuantum**
- **Xanadu**
- **ORCA Computing**

Neutral Atom Qubits

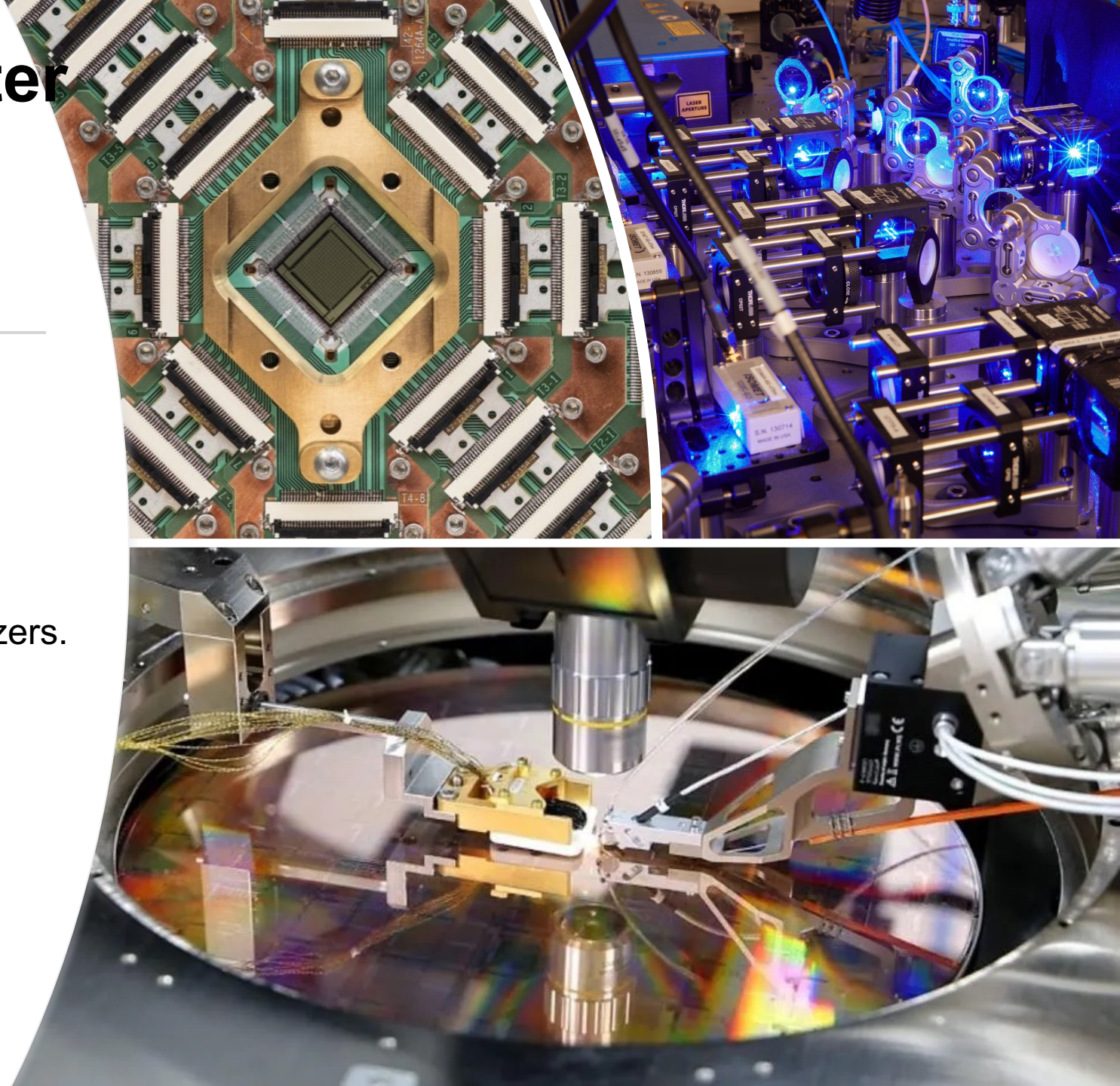
Neutral atoms trapped in optical lattices or tweezers.

- **QuEra Computing**
- **ColdQuanta**
- **Atom Computing**

Quantum Annealers

Specialized devices for optimization problems, leveraging quantum tunneling.

- **D-Wave Systems**



THE CENTRAL QUESTION

How can errors be diagnosed without measuring the encoded quantum information?

Syndrome measurements reveal an error class while preserving the logical superposition.

Prediction: state what should change in the first experiment and what must remain invariant.

KEY TERMS

logical qubit
syndrome
code distance
fault tolerance

MODEL

encode -> noisy channel -> syndrome ->
correction -> decode

FIRST WORKED EXPERIMENT

Start with one case small enough to check by hand.

1. Write the input and prediction
2. Apply the operation
3. Compare the observed evidence

Evidence to keep: logical error rate, syndrome table, and uncorrectable cases. Label basis order, shots, and simulator assumptions.

EXPERIMENT

Enumerate bit-flip patterns for the three-qubit repetition code and test recovery.

THE CENTRAL QUESTION

How do physical qubits change the circuit we can actually execute?

Connectivity, native gates, coherence, speed, and measurement jointly define a platform's usable capability.

Prediction: state what should change in the first experiment and what must remain invariant.

KEY TERMS

native gate
coupling map
coherence
calibration

MODEL

logical circuit -> placement -> routing ->
native gates -> schedule

FIRST WORKED EXPERIMENT

Start with one case small enough to check by hand.

1. Write the input and prediction
2. Apply the operation
3. Compare the observed evidence

Evidence to keep: depth, two-qubit gates, SWAPs, and output-distribution distance. Label basis order, shots, and simulator assumptions.

EXPERIMENT

Transpile one circuit to all-to-all and linear coupling maps; verify semantics and count overhead.

Current hardware comparison

Update the illustrative platform and vendor examples with dated primary sources.

Compare encoding, control, readout, connectivity, coherence, and native operations.
Separate physical and logical qubits.

Logical qubits and syndrome measurement

Develop one small code, its encoding, and a syndrome table.

Show which errors it corrects and which it cannot. Explain why syndrome measurement can preserve logical information.

Fault tolerance and overhead

Connect physical error rates, code distance, and logical failure probability.

State the assumptions behind a threshold claim and provide a worked resource example.