



BMBF



**BLACK FOREST
QUANTUM**

HELMHOLTZ

RESEARCH FOR GRAND CHALLENGES



Supraleitende Schaltkreise für Quantencomputing

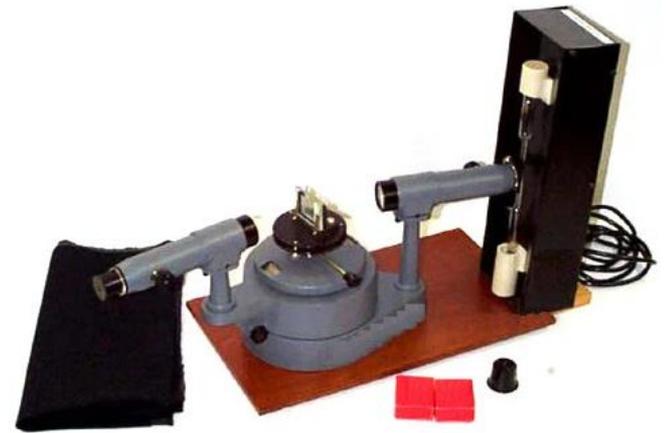
Dr. Thomas Reisinger

**IBM
Quantum System One
- 27 Qubits
in Ehningen**



Atome

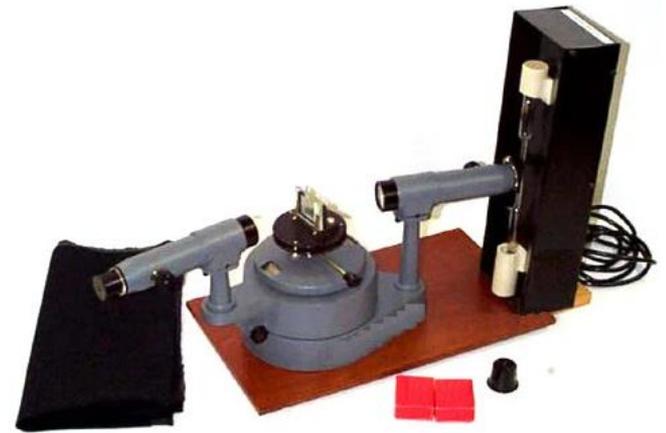
➡ Natürliche Quantensysteme



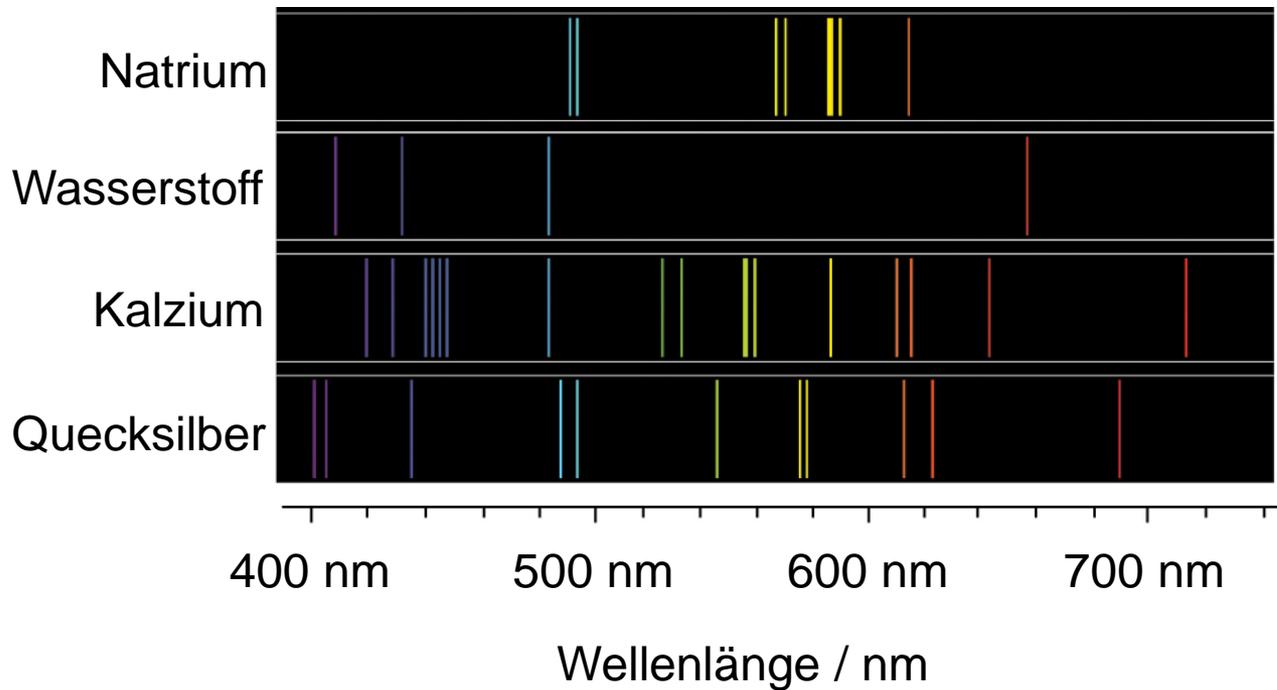
Spektrograph mit
Wasserstoffröhrenlampe

Atome

➡ Natürliche Quantensysteme

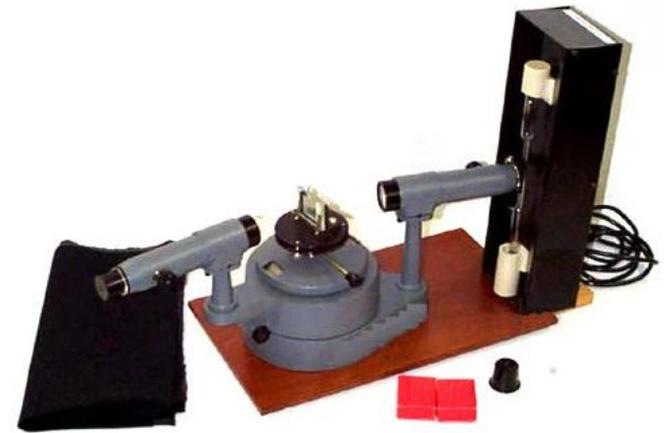


Spektrograph mit Wasserstoffröhrenlampe

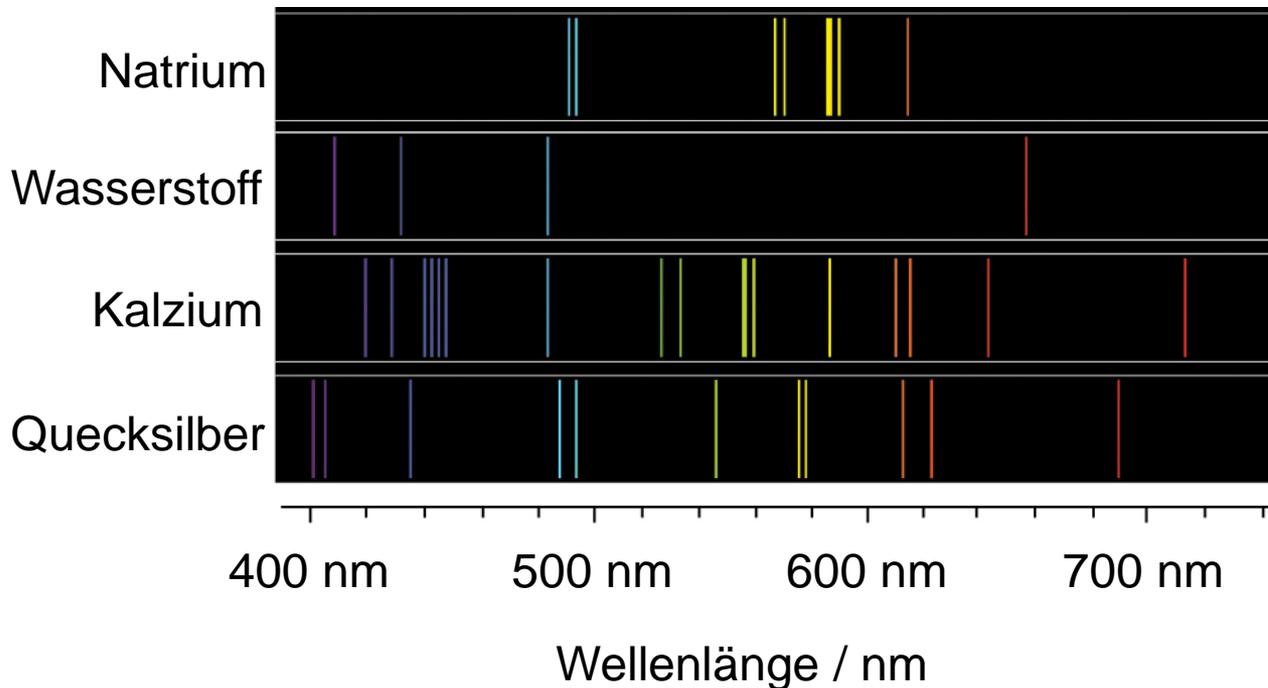


Atome

➡ **Natürliche Quantensysteme**

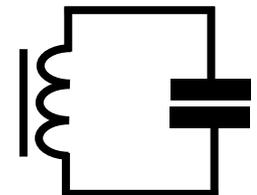


Spektrograph mit Wasserstoffröhrenlampe



Künstliche Atome?

**Quantensysteme
entwerfen,
wie einen
Schaltkreis.**



Viele Qubits
→ Viele Mikrowellenkabel

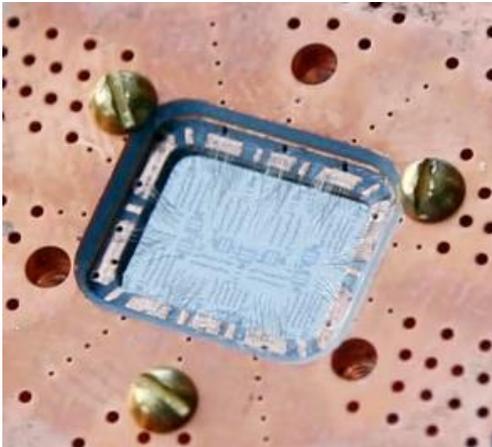
Millikelvin Kryostat

Raumtemperatur Elektronik
für Mikrowellenpulse



Filter und
Dämpfungsglieder

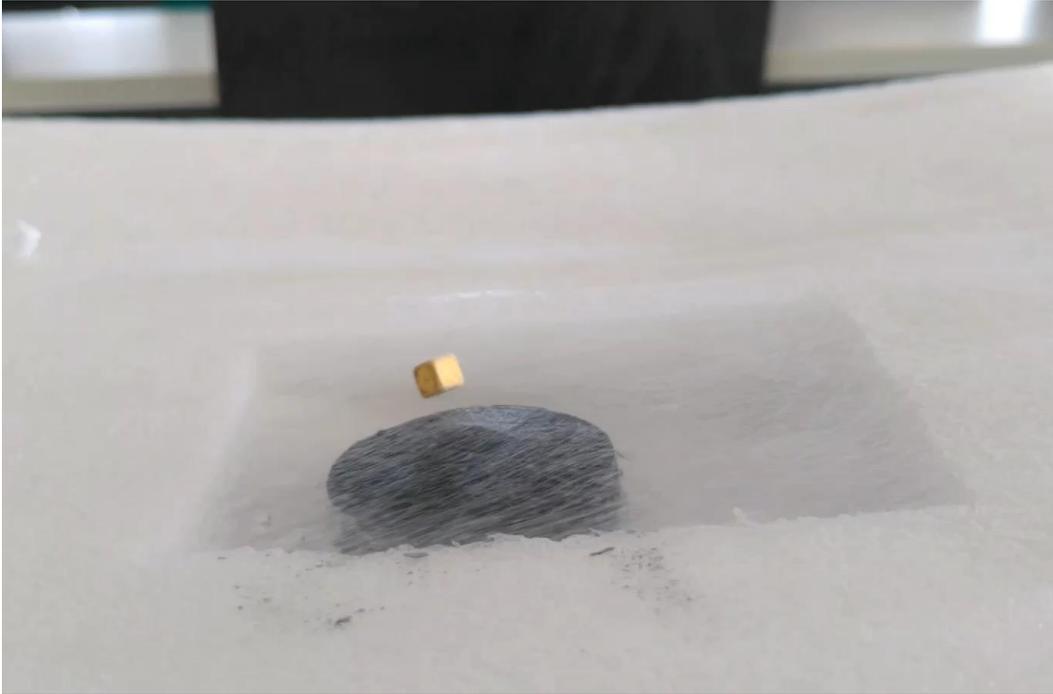
Mikrowellen-
verstärker



Chip aus Saphireinkristall
mit Supraleitenden Leiterbahnen
(in Gehäuse)

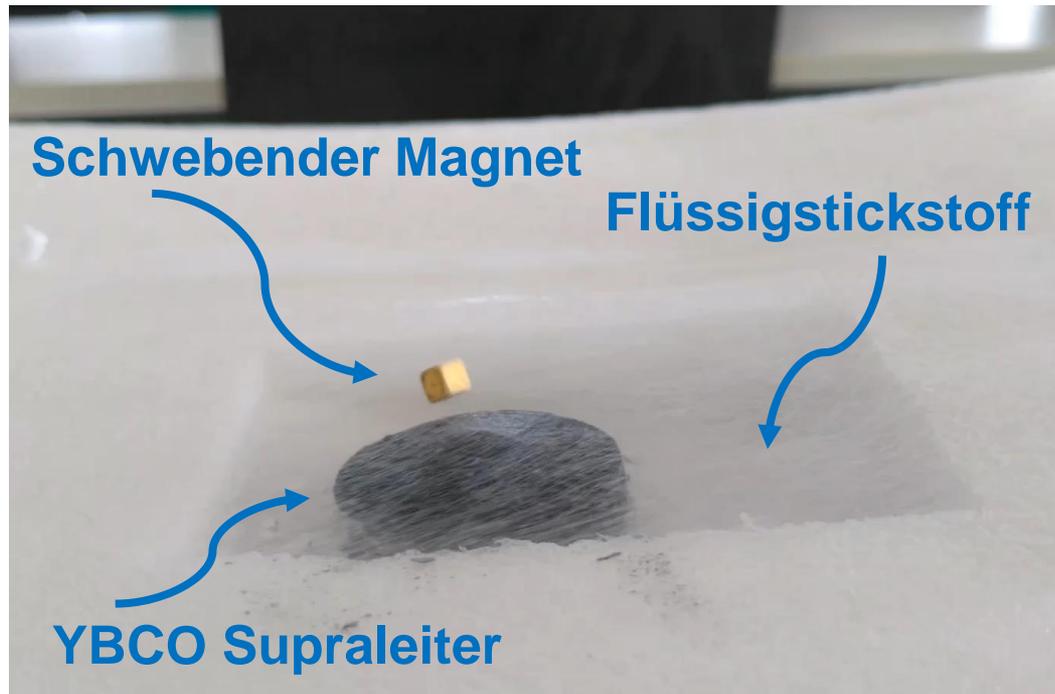
IBM
Quantum System One

Supraleitung



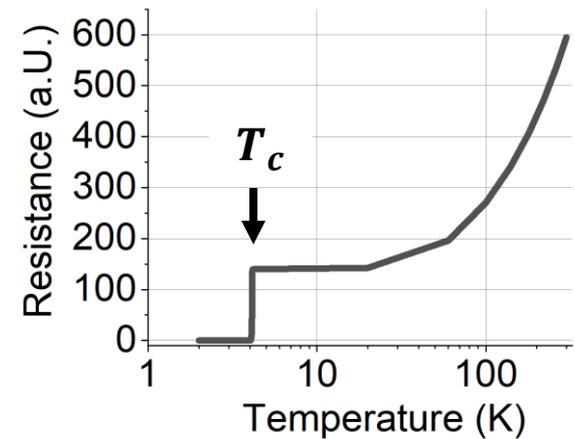
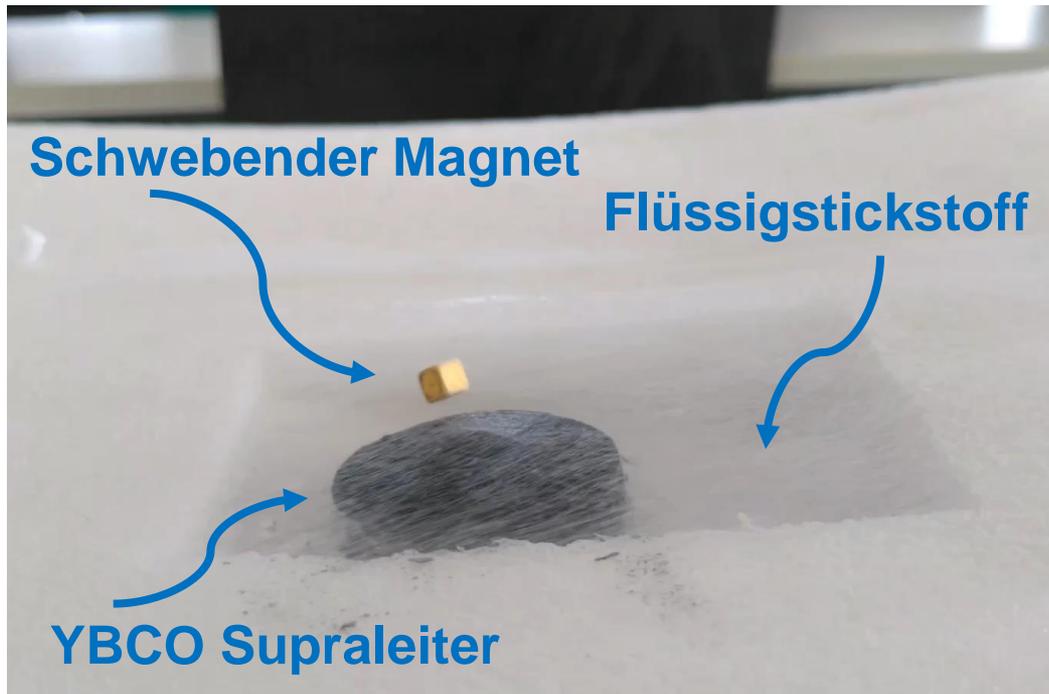
Supraleitung

- Meißner Effekt



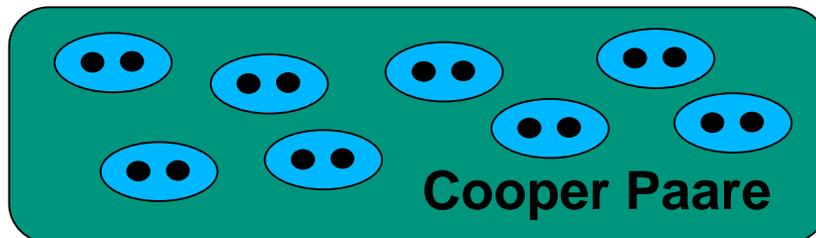
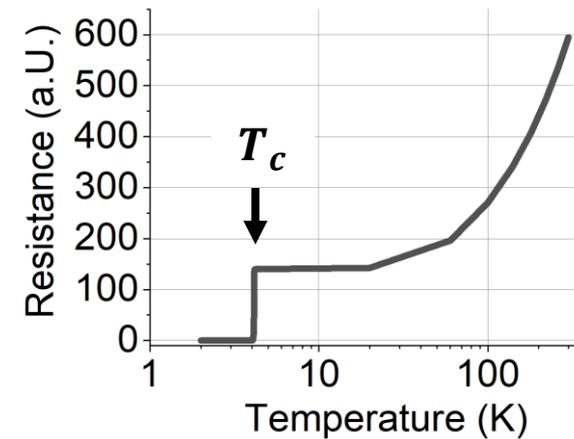
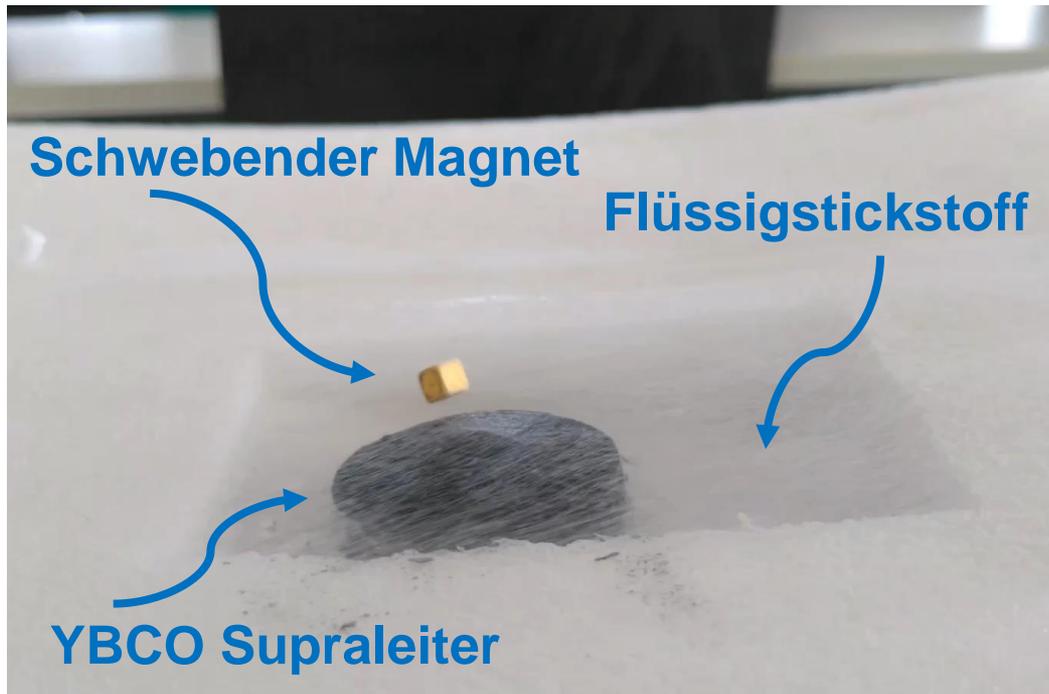
Supraleitung

- Meißner Effekt
- DC Widerstand verschwindet



Supraleitung

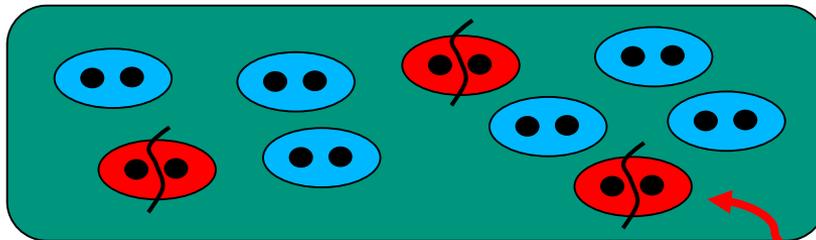
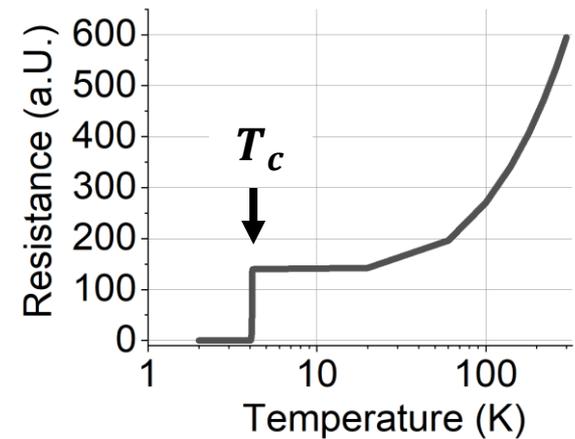
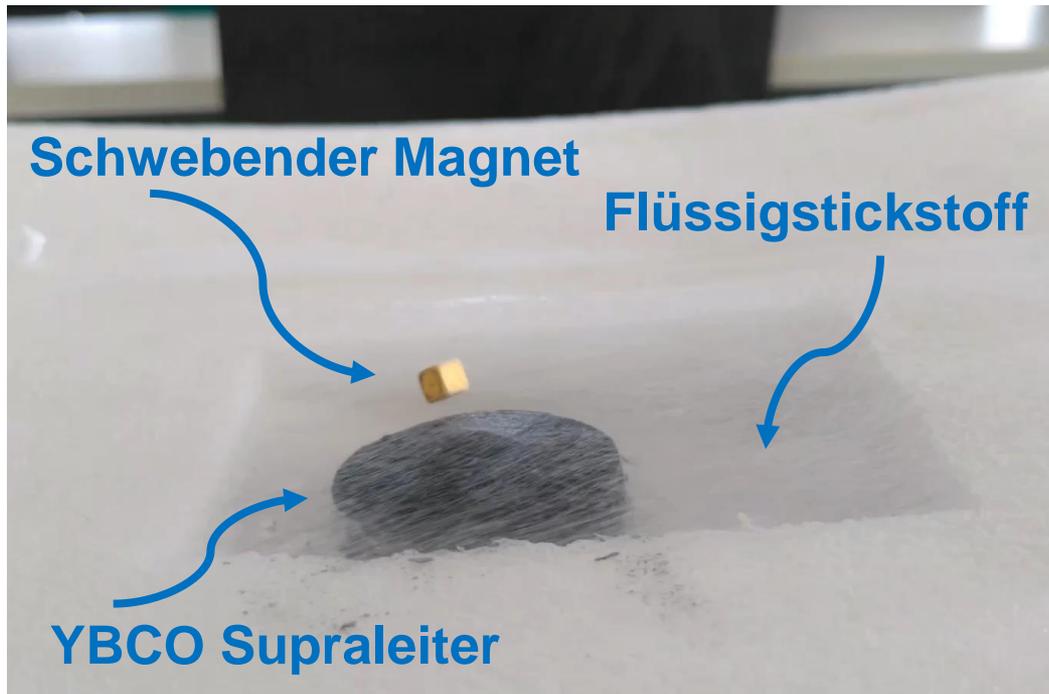
- Meißner Effekt
- DC Widerstand verschwindet
- Bardeen-Cooper-Schrieffer Theorie



$$0 < T < T_c$$

Supraleitung

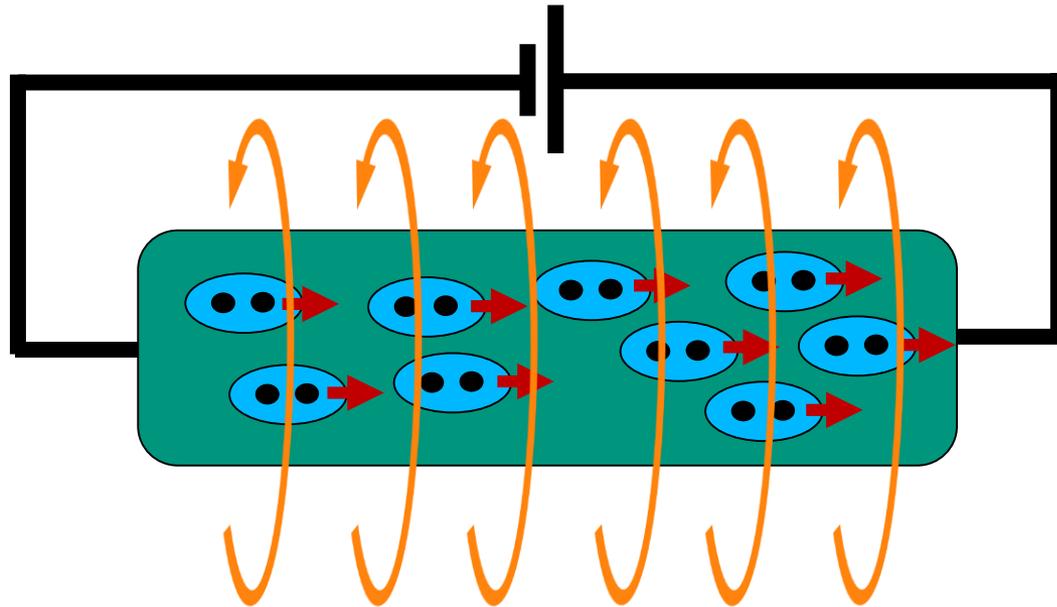
- Meißner Effekt
- DC Widerstand verschwindet
- Bardeen-Cooper-Schrieffer Theorie



$$0 < T < T_c$$

Quasi-Partikel

Supraleitung – Kinetische Induktivität



Magnetfeld →
Geometrische Induktivität

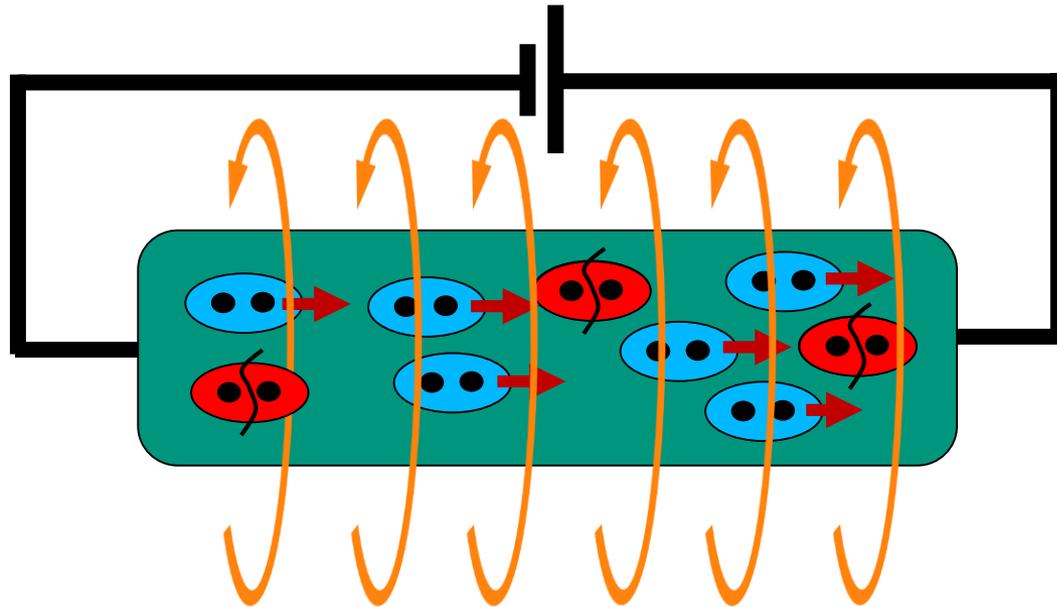
$$E_B = \frac{1}{2} L_g I^2,$$

$$L_g \sim l \left(\ln \left(\frac{2l}{r} \right) - 1 \right)$$

Kinetische Energie der
Cooper Paare →
Kinetische Induktivität

$$E_k = \frac{1}{2} L_k I^2, \quad L_k = \left(\frac{m_e}{2n_s e^2} \right)$$

Supraleitung – Kinetische Induktivität



Magnetfeld →
Geometrische Induktivität

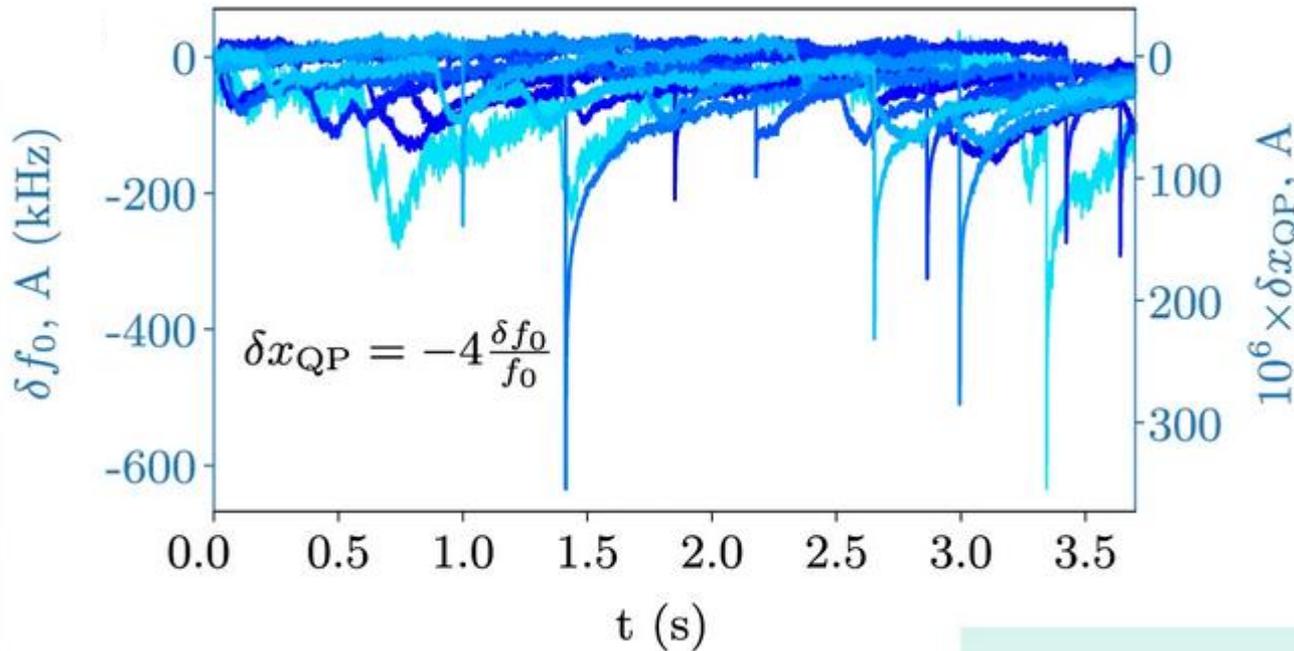
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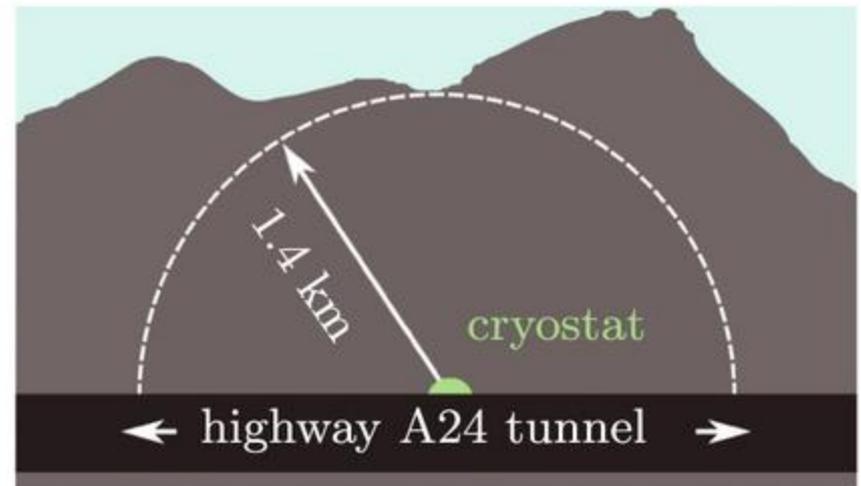
Quasi-Partikel Ausbrüche



Änderung der
Frequenz durch
ionisierende
Strahlung

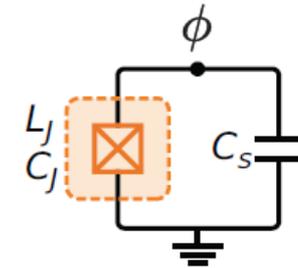
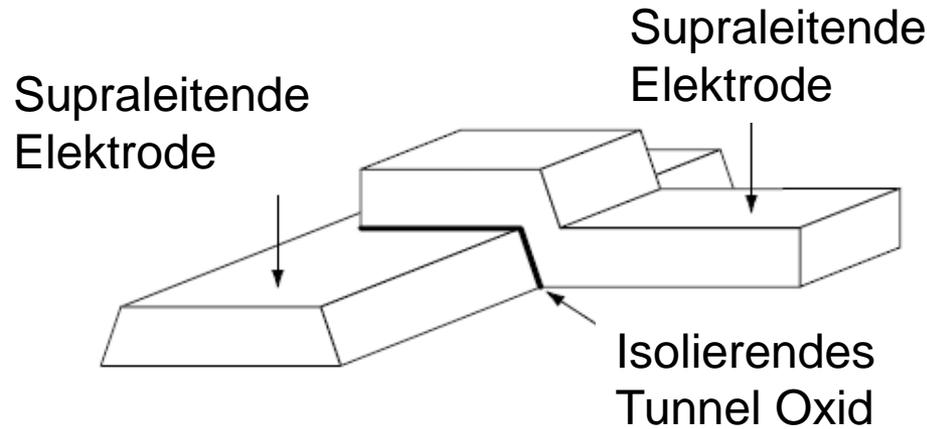
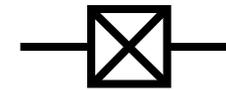
→ Korrelierte
Fehler

**Schutz vor
Muonen im
Untergrundlabor**

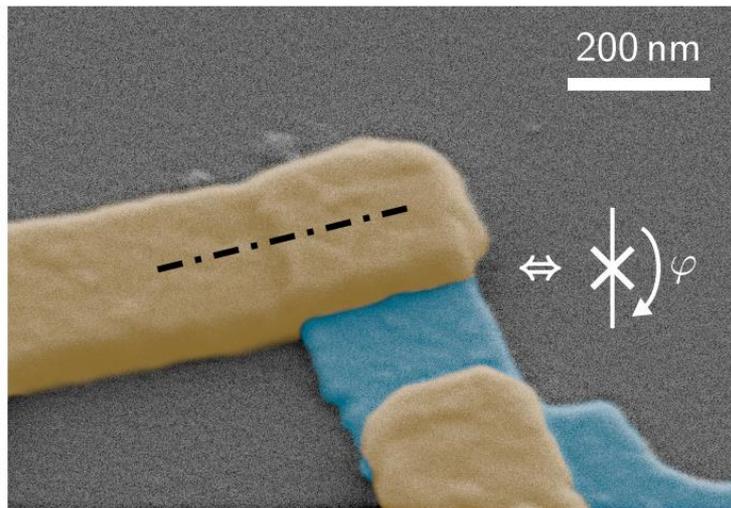


Cardani et al.
Nature Communications (2021)

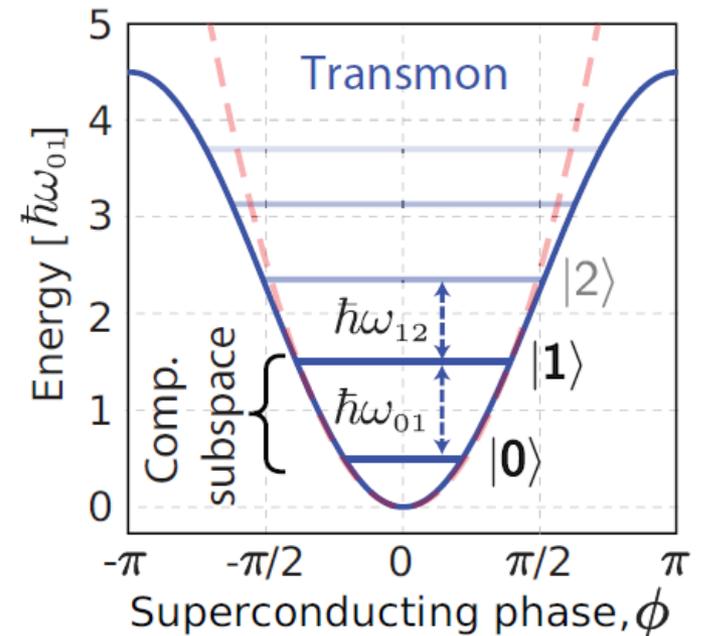
Josephson Kontakte



Josephson Junction adds Anharmonicity

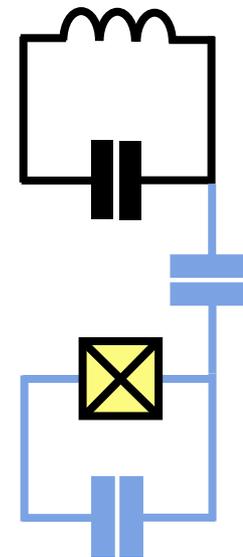
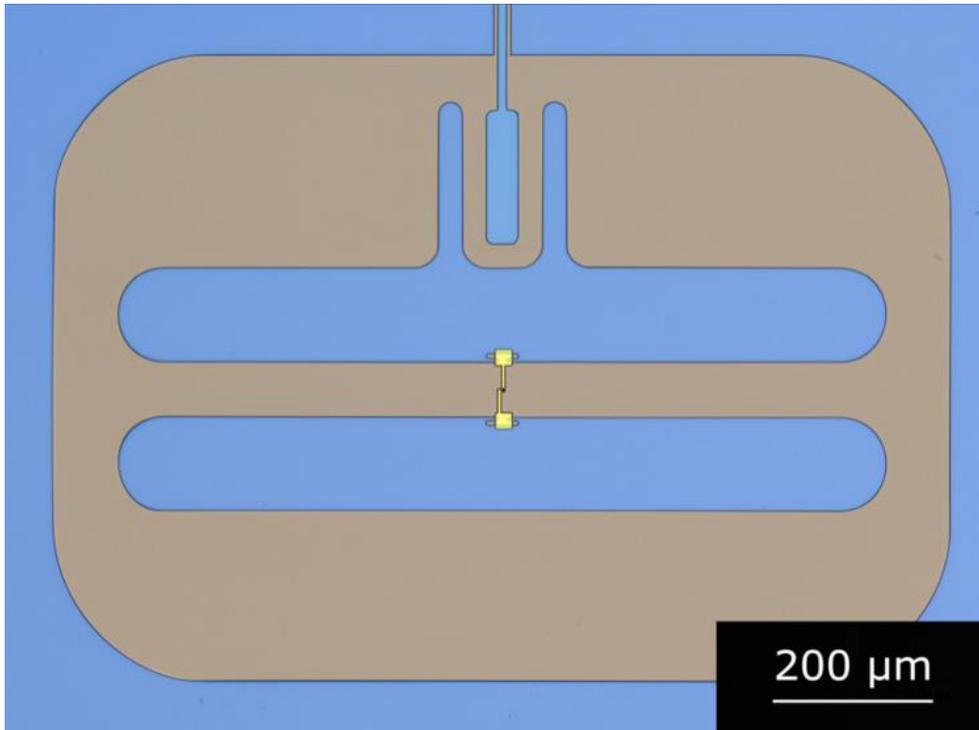


Willsch & Rieger et al.
Nature Physics (2024)



Transmon Qubit

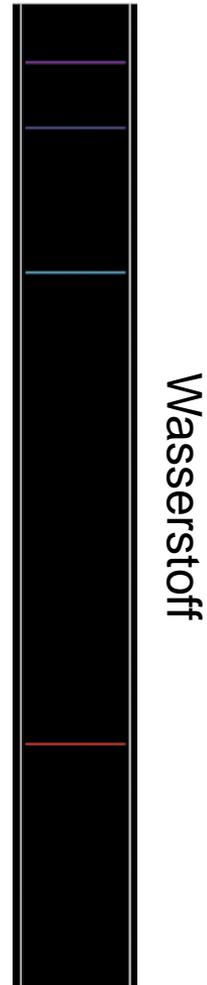
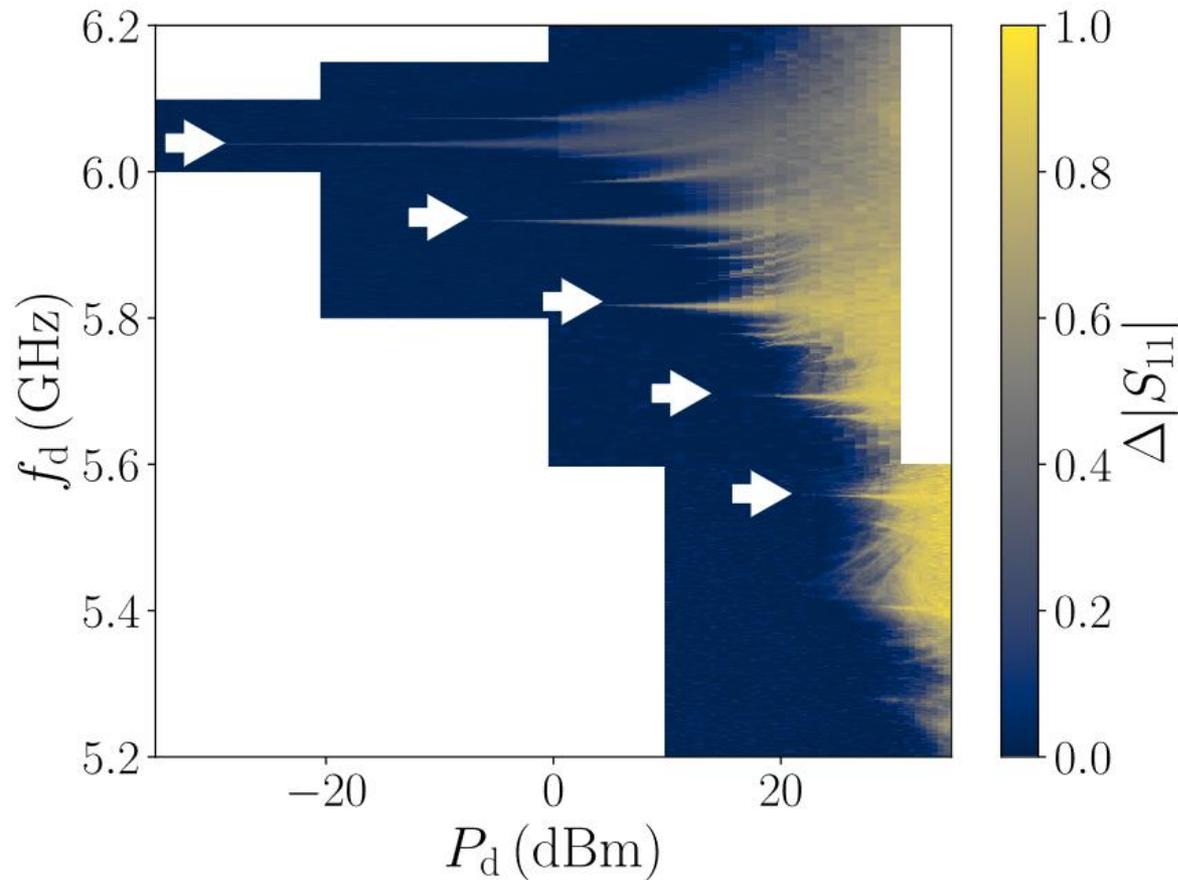
Erfinder:
Robert J. Schoelkopf,
Michel Devoret,
Steven M. Girvin



Auslese-
Resonator

Transmon
Qubit

Transmon Spektrum



Willsch & Rieger et al.
Nature Physics (2024)

Quantenprozessoren

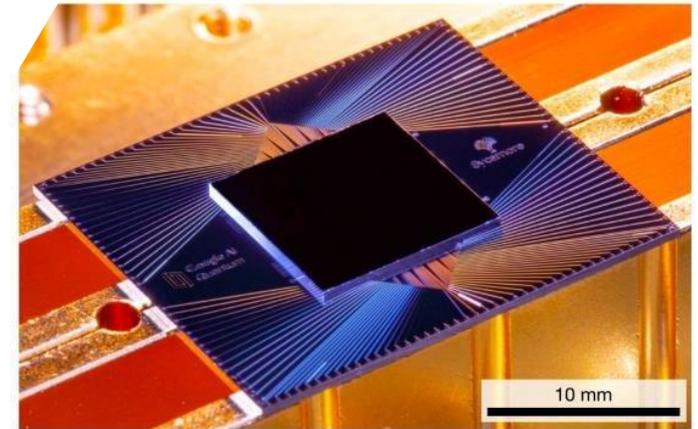
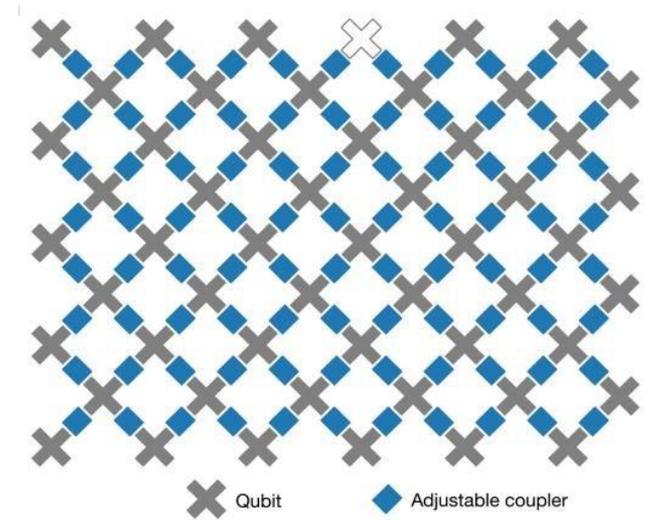
- Kommerzialisierung: IBM, Google, Rigetti, IQM, Alice & Bob, usw.
- BMBF Projekte Qsolid und GeQCoS

Quantenüberlegenheit

Fehlerkorrektur

Fehlertolerante Qubits

Qubit Materialien & Prozesse

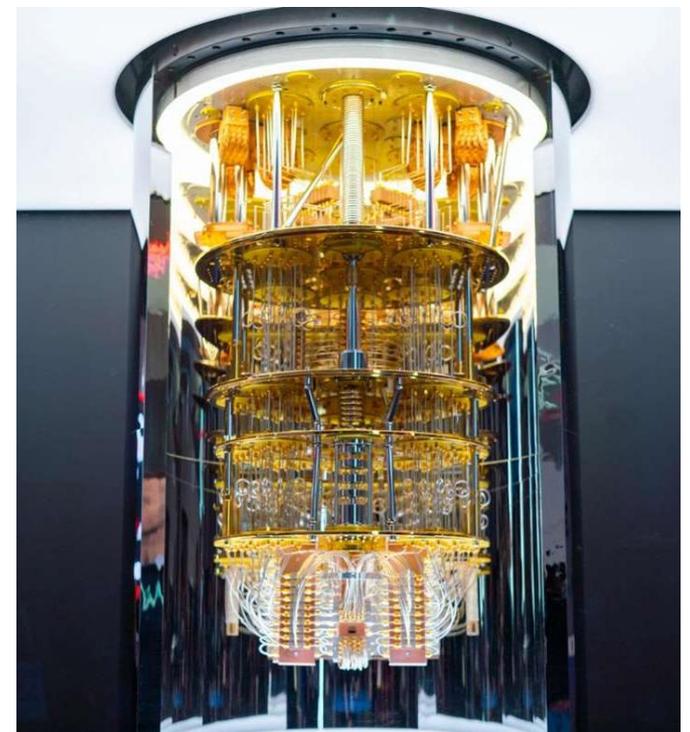


Google's Sycamore Prozessor

Run a program on a real Quantum Computer:
<https://docs.quantum.ibm.com/start/hello-world>

Zusammenfassung

- Supraleitung
- Quantencomputer Aufbau
- Aktuelle Themen
 - Quasipartikelausbrüche
 - Transmon Qubit





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Denis

Ritika

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Markus

Nico G.

Dennis

Simon I.

Martin

Mathieu

Simon II.

Patrick

Sören

Mahya

Ioan



Lucas



Christian



Haoran



Jasmin



Pierre-Adrien, Dirk,...