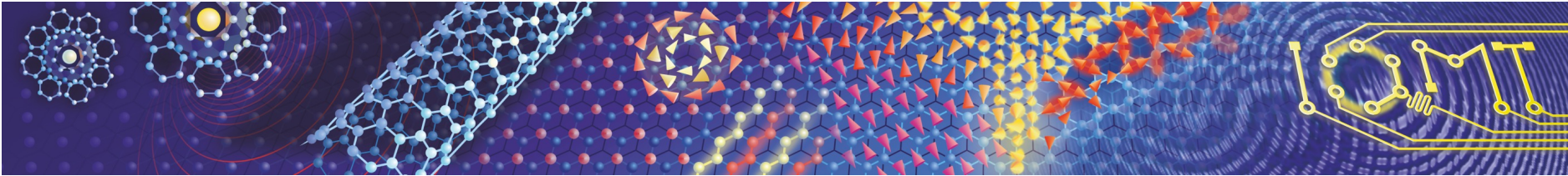


Quantencomputer in der Gegenwart: der aktuelle Stand der Forschung

Prof. Dr. Wolfgang Wernsdorfer

Institute of Quantum Materials and Technologies (IQMT)



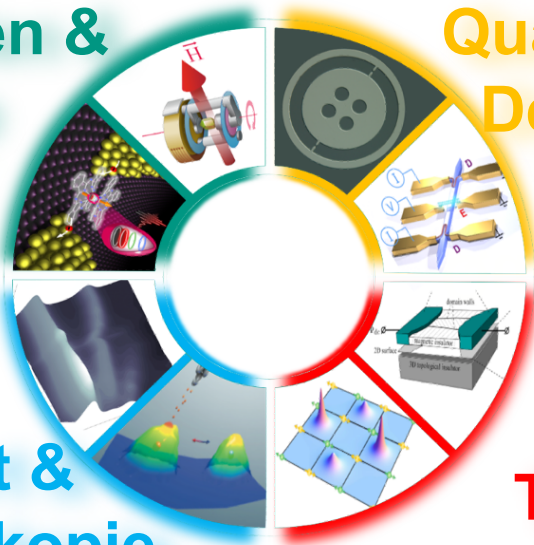


**Materialien &
Moleküle**

**Quantum
Devices**

**Transport &
Spektroskopie**

Theorie

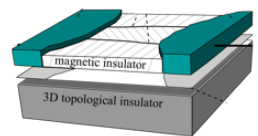
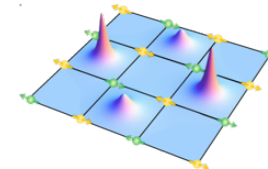
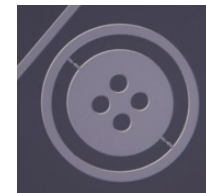
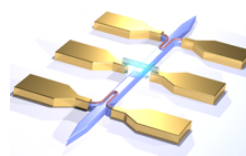
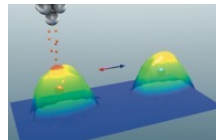
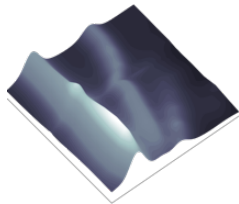
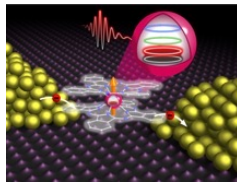
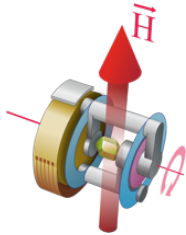


- Gründung 01/2020
- Entwicklung neuer Quantenmaterialien
- Funktionalisierung
- Bausteine für Quantentechnologien und Quantencomputer
- 8 Abteilungen, 17 Professoren

HELMHOLTZ QUANTUM

2022: ca. 110 Mitarbeiter (45 Dauerstelle)
Personalbudget ca. 7M€/a
(80% HGF, 20% Drittmittel)

IQMT unfolded



New Quantum
Materials

Molecular Quantum
Systems

Quantum Materials
Spectroscopy

Quantum
Transport

Quantum Optical
Devices

Quantum Circuits

Theory of Quantum
Materials

Theory of
Mesoscopic
Quantum Systems

C. Meingast

M. Ruben

M. Le Tacon

W. Wulfhekel

R. Krupke

W. Wernsdorfer

J. Schmalian

A. Mirlin

NWG Böhmer

AG Ruben

AG Le Tacon

AG Beckmann

AG Krupke

AG Pop

AG Garst

AG Gornyi

AG Meingast

AG Mayor

AG Schuppler

AG Gerhard

AG Hunger

AG Ustinov

AG Schmalian

AG Mirlin

AG Schneider

AG Powell

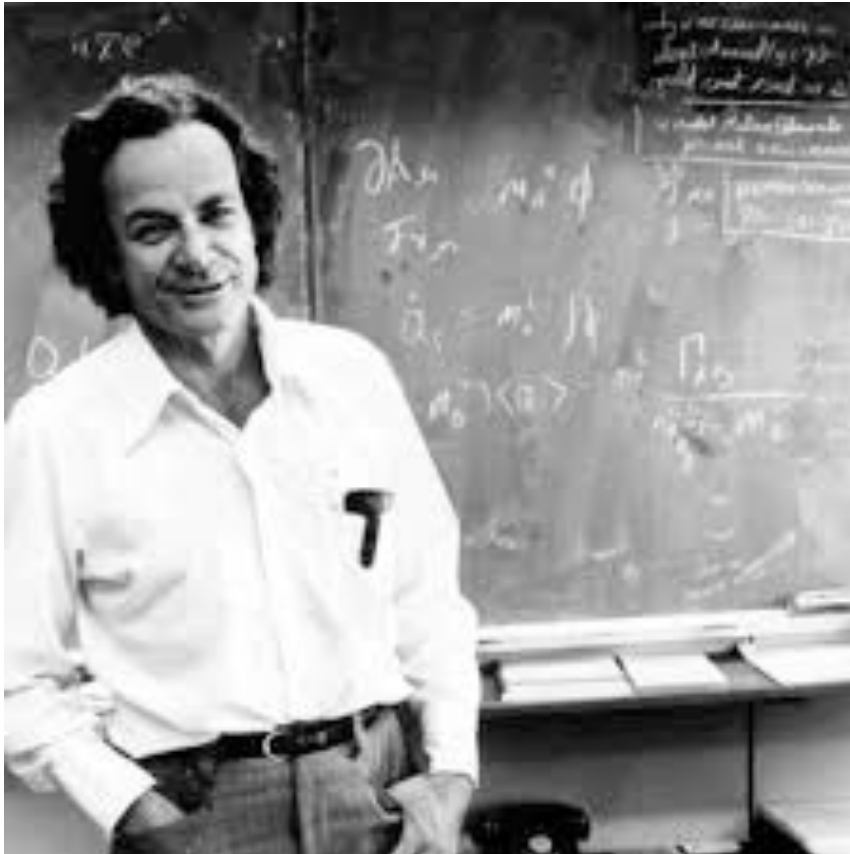
AG Weber

AG Kappes

AG Wernsdorfer

AG Shnirman

The whole world is quantum



Richard Feynman

Is it possible to build computers that use the laws of quantum mechanics to compute?

“Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy.”

Simulating physics with computers,
R. Feynman,
Int. J. Theor. Phys., 21, 467 (1982)

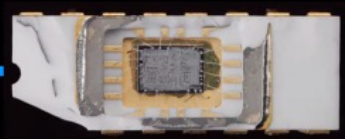
Why Quantum Computing? Why now?

1958



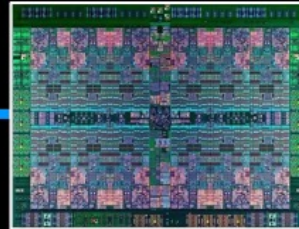
First integrated circuit
Size $\sim 1\text{cm}^2$
2 Transistors

1971



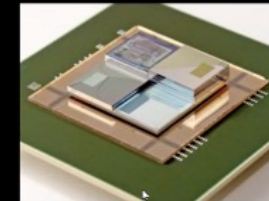
Moore's Law is Born
Intel 4004
2,300 transistors

2014



IBM P8 Processor $\sim 650\text{ mm}^2$
22 nm feature size, 16 cores
> 4.2 Billion Transistors

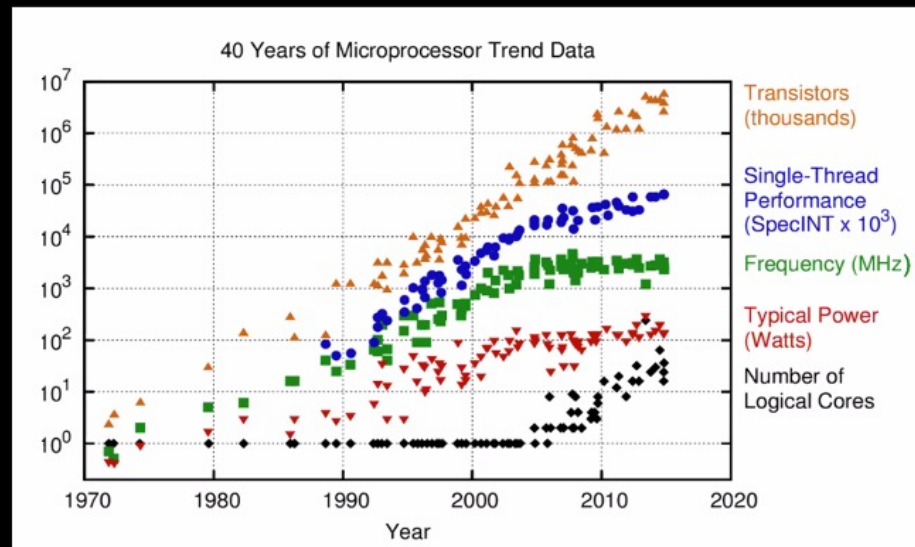
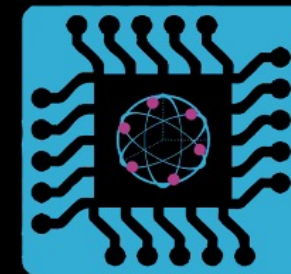
Alternative (co-existing) architectures:
next generation systems (e.g. 3D)



neuromorphic (cognitive)



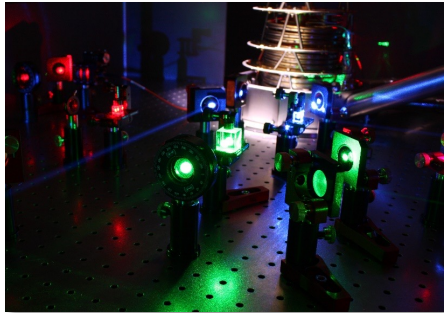
quantum computing



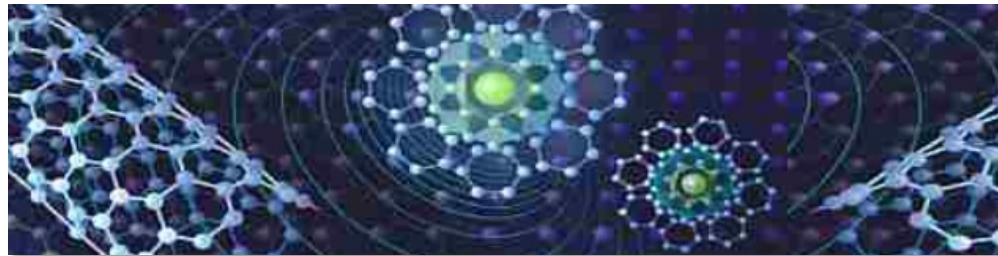
Quantum Technologies

- The second quantum revolution and its applications

Quantum Sensing



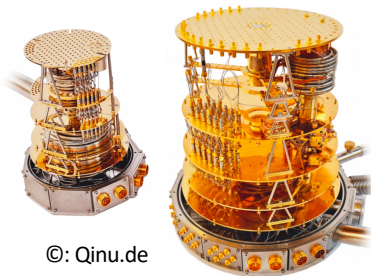
Quantum Materials Fundamental Research



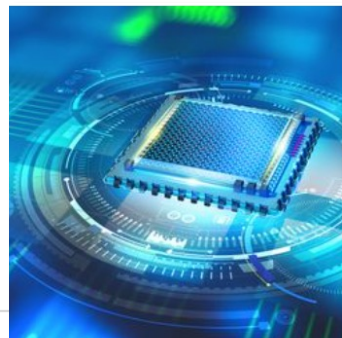
Quantum Communication



Infrastructure



Quantum Computing

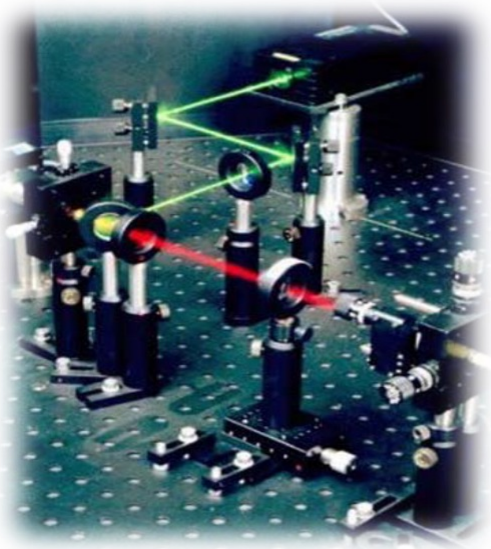


Quantum Simulation

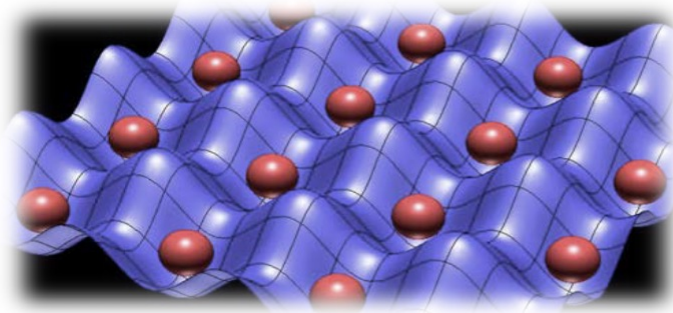


Quantum bits (qubits)

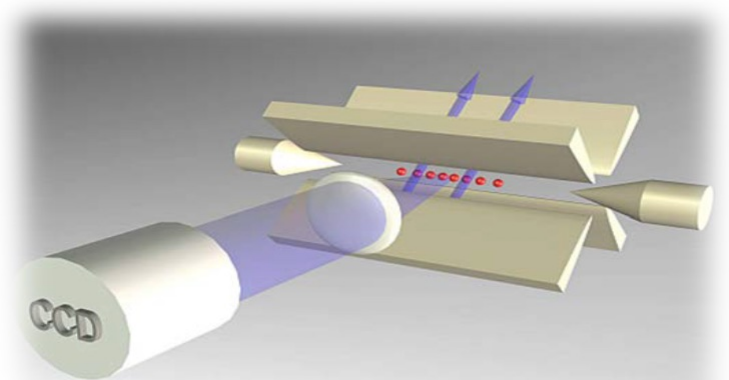
photons



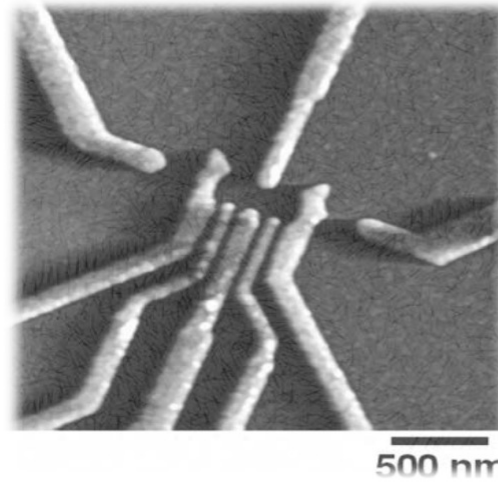
atoms



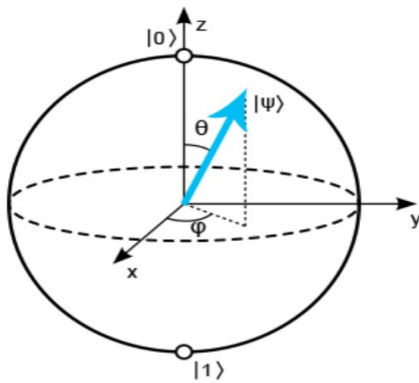
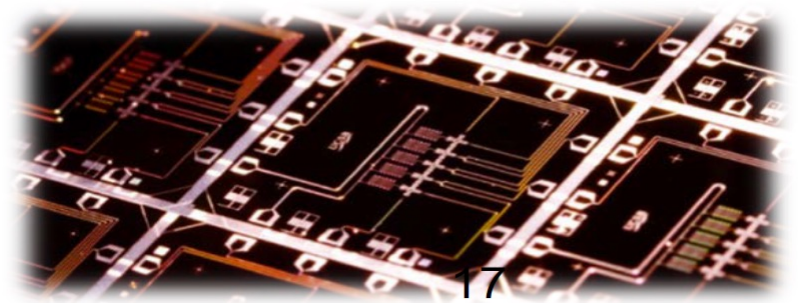
ions



semiconductors

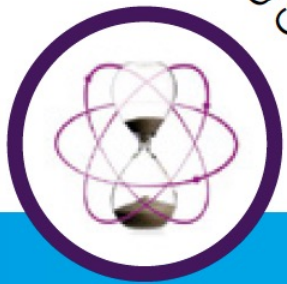


superconductors

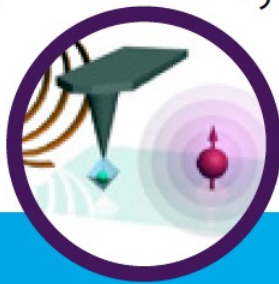


Quantum Technologies Timeline

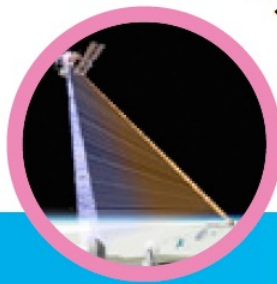
ATOMIC
QUANTUM
CLOCK



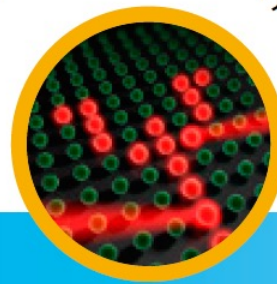
QUANTUM
SENSOR



INTERCITY
QUANTUM
LINK



QUANTUM
SIMULATOR



QUANTUM
INTERNET



UNIVERSAL
QUANTUM
COMPUTER

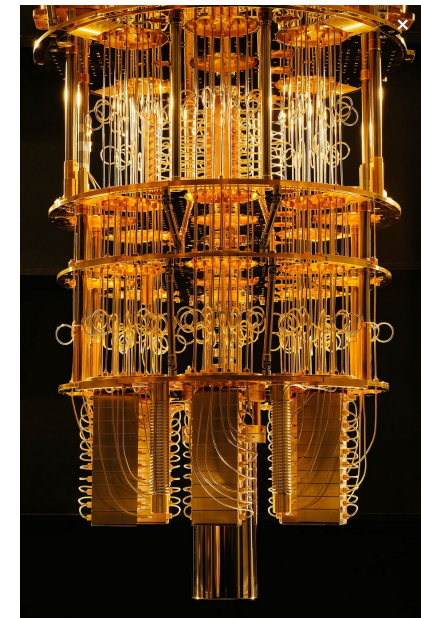
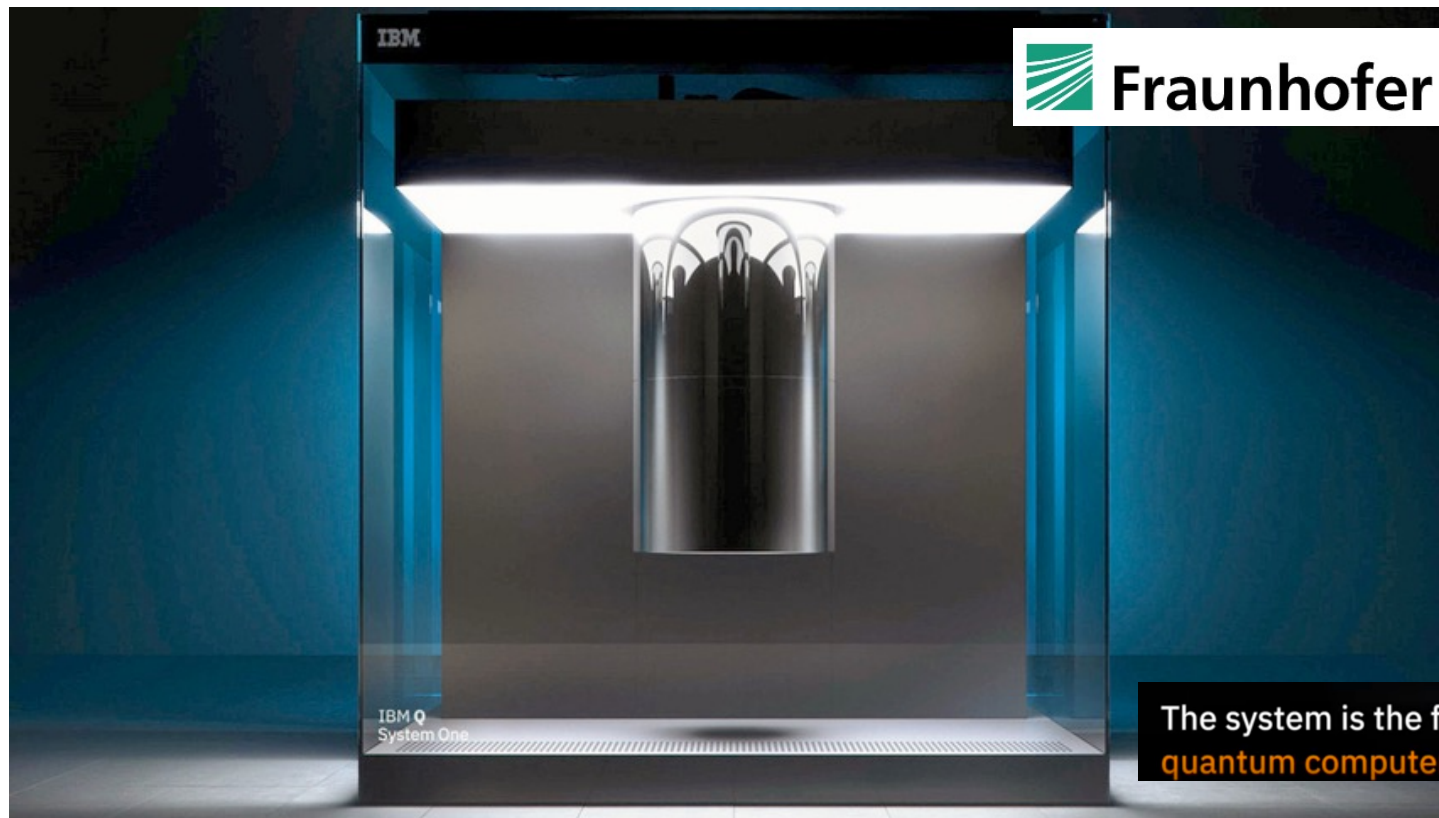


2015

2035

Einweihung der Forschungsplattform für Quantencomputer

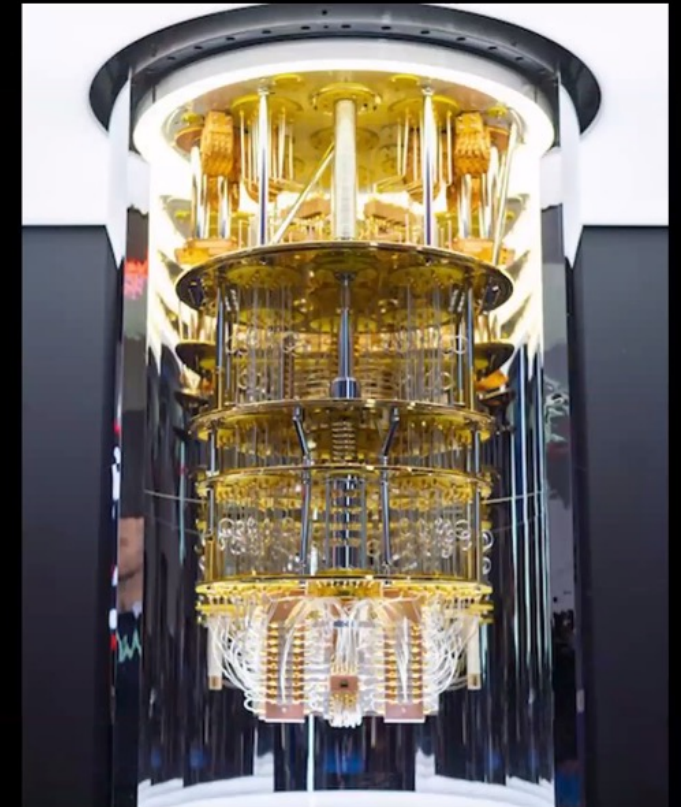
Das erste IBM Quantum System One in Europa,
in Ehningen bei Stuttgart (15. Juni 2021)



The system is the first **universal approximate superconducting quantum computer** to operate outside the research lab

Online QC systems - IBM

Name	Qubits	QV	Status	Total pending jobs	Processor type	Features
ibmq_casablanca	7	32	● Online	377	Pigeon r1	📅
ibmq_bogota	5	32	● Online	623	Canary r3	📅
ibmq_santiago	5	32	● Online	57	Canary r3	-
ibmq_rome	5	32	● Online	43	Canary r3	📅
ibmq_athens	5	32	● Online	70	Canary r3	-
ibmq_16_melbourne	15	8	● Online	9583	-	-
ibmq_5_yorktown	5	8	● Online	4368	-	-
ibmq_armonk	1	-	● Online	0	Emu r1	✓
ibmq_qasm_simulator	32	-	● Online	1	-	-



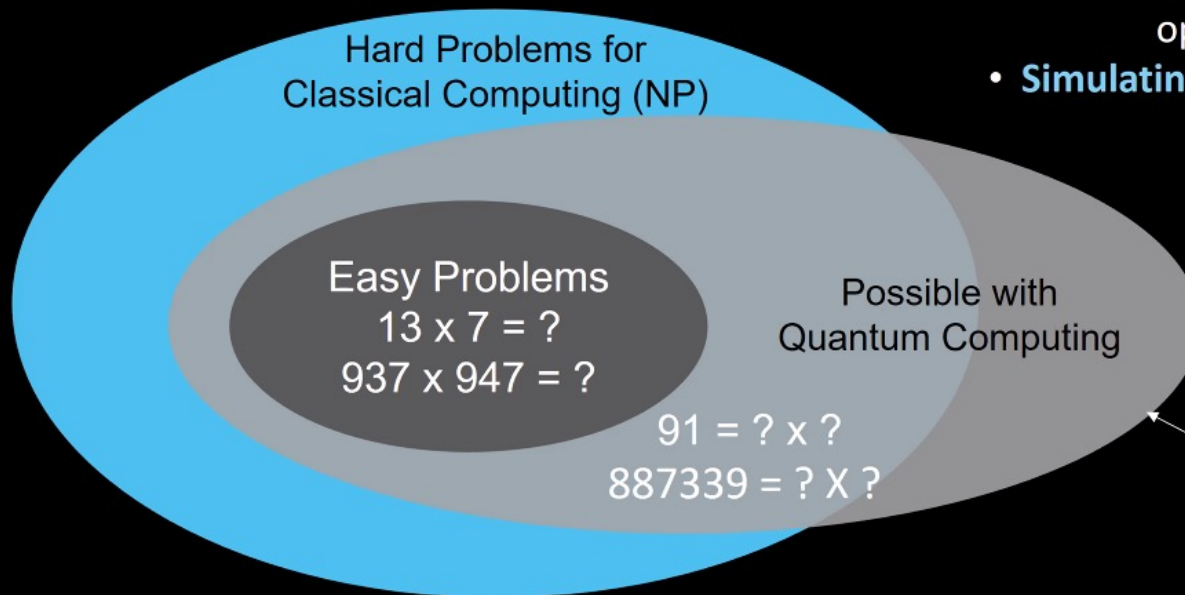
Quantum Computing as a path to solve intractable problems

Many problems in business and science are too complex for classical computing systems

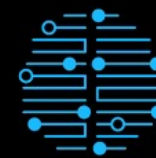
“hard” / intractable problems:

(exponentially increasing resources with problem size)

- **Algebraic algorithms** (e.g. factoring, systems of equations) for machine learning, cryptography,...
- **Combinatorial optimization** (traveling salesman, optimizing business processes, risk analysis,...)
- **Simulating quantum mechanics** (chemistry, material science,...)



Material,
Chemistry



Machine
Learning



Optimization

The Quantum Advantage – Storing quantum states

How much **memory** is needed to store a quantum state?

# qubits/	quantum state	coefficients	# bytes
1	$a 0\rangle + b 1\rangle$	$2^1 = 2$	16 Bytes
2	$a 00\rangle + b 01\rangle + c 10\rangle + d 11\rangle$	$2^2 = 4$	32 Bytes
8		$2^8 = 256$	2kB
16	...	$2^{16} = 65'536$	512 kB
32	...	~4 billion	32 GB
64	...	~ information in internet	128 EB (134 million GB)
256	...	~ # of atoms in universe	...



<https://www.helmholtz.de/forschung/quantentechnologie/computing/>

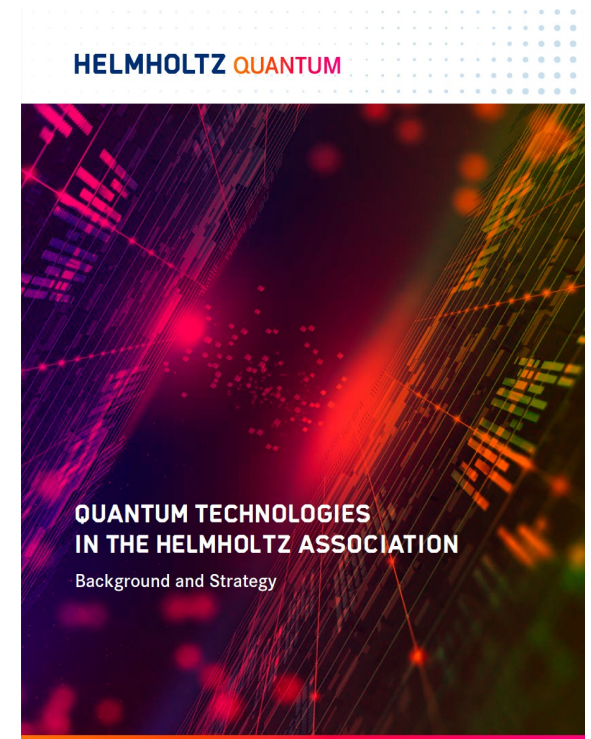
RESEARCHING THE SECOND QUANTUM REVOLUTION

Quantum technologies in the Helmholtz Association

Umsetzung der PoF IV am KIT

P2 NACIP – Quantum

- Strong participation to the Helmholtz Roadmap for Quantum Technologies
- Intensive response to the many BMBF quantum calls (next slide)
- NFDI project DAPHNE
- Approval of the new GradUP “KIT Graduate School on Quantum Matter” (Coord. Prof. M. Garst)
- New Nanomat Focus Group (exchange platform with industry) „Quantum Materials and Technologies“



<https://www.helmholtz.de/forschung/quantentechnologie/computing/>

BMBF Call	Project	Partners	Budget (Total)	Budget (KIT)	Status
Schlüsselkomponenten für QT	PtQube (2020-2023)	KIT, TransMIT GmbH Entropy GmbH	1.4M€	0.9k€	Started
Quantenprozessoren und Technologien für QC	GeQCOS (2021-2025)	WMI, IAF, Infineon, KIT, FAU, FZJ	16.1M€	3.2M€	Started
Selbstbestimmt in der digitalen Welt	QR.X (2021-2024)	KIT + ca. 30 weitere deutsche Partner	35M€	1.2M€	Started (1.8.21)
Quantum Computing Demonstrators	Spining	KIT + ca. 30 German Partners	36.5M€	1M€	Expected (10-20% cut) 1.1.22
	Qsolid	KIT + ca. 40 German Partners	~70M€	5.7 M€	Final decision exp. 12/21
Grand Challenge der Quantenkommunikation	NEQSiS	PIs: Hunger + 2 German Partners	1.05M€	350 k€	Begin exp. 1.11.21
Enabling Technologies für die QT	qBriqs	KIT, IAF, PTB + Rosenberger, Stahl	1.9 M€	450 k€	Begin exp. 1.11.21
Nachwuchswettbewerb Quantum Futur Runde 2	DiamondNanoN MR	KIT	3.9 M€	3.9 M€	Step 2 in preparation

Umsetzung der PoF IV am KIT

P2 NACIP - Quantum

■ Pending recruitments:

- T1/T2: New UB professorships get affiliation with IQMT and positions
 - W3 Quantum Computing (Fiebiger Professorship)
 - W3 Quantum Optics (NF Kalt)
 - W3 Quantum Circuits (professorship in Stuttgart)
 - W1 TT-Prof. for Quantum control of spins on surfaces

■ YigPrepPro:

- 2021 Dr. Mehdi Frachet (T1)

Holistic investigation of quantum materials under uniaxial strain

- 2021 Dr. Eider Berganza (T1)

Artificial Spin Ice systems

**KOMPETENZZENTRUM
QUANTENCOMPUTING**
Baden-Württemberg



Teilen

FÖRDERPROGRAMM



Text vorlesen



Drucken



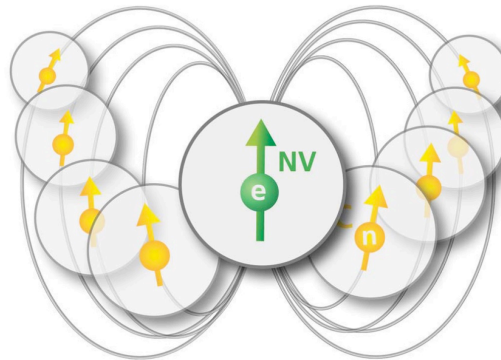
Als PDF speichern

Verbundforschungsprojekte im Rahmen des Kompetenzzentrums Quantencomputing Baden- Württemberg

<https://wm.baden-wuerttemberg.de/de/service/foerderprogramme-und-aufrufe/liste-foerderprogramme/verbundforschungsprojekte-im-rahmen-des-kompetenzzentrums-quantencomputing-baden-wuerttemberg/>

QC-4-BW

Entwicklung und Benchmarking eines Diamant-basierten, spintronischen
Quantenregisters für einen aufskalierbaren Quantenprozessor



FHI für Angewandte Festkörperphysik



FHI für Chemische Technologie



Universität Stuttgart



Universität Ulm



Karlsruher Institut für Technologie



Universität Konstanz

Assoziierte Partner: BASF, Merck, IBM, HQS, Bosch, Q, Ant, SVA, Evatec, attocube, Cynora, Diehl, Quantum Brilliance

Competence Network Quantum Technology in BW | QTBW.net

<https://iqst.org/initiatives/qtbwnet.html>



Partner Institution	Contact	Institute
University of Konstanz	Guido Burkard	Condensed Matter Theory and Quantum Information
University of Freiburg	Tobias Schaetz	Experimental Atomic, Molecular, and Optical Physics
University of Tuebingen	Daniel Braun	Theoretical Quantum Optics
University of Karlsruhe	Wolfgang Wernsdorfer	Experimental Solid State Physics
University of Stuttgart	Sebastian Loth	Institute for Functional Matter and Quantum Technologies co-ordinator QTBW.net
University of Heidelberg	Philipp Preiss	Institute for Physics and Center for Quantum Dynamics
Ulm University	Joachim Ankerhold	Institute for Complex Quantum Systems co-ordinator QTBW.net
Max Planck Institute for Solid State Research, Stuttgart	Christian Ast	Nanoscale Science
Fraunhofer Institute for Applied Solid State Physics (IAF), Freiburg	Oliver Ambacher	

QUSTEC COFUND

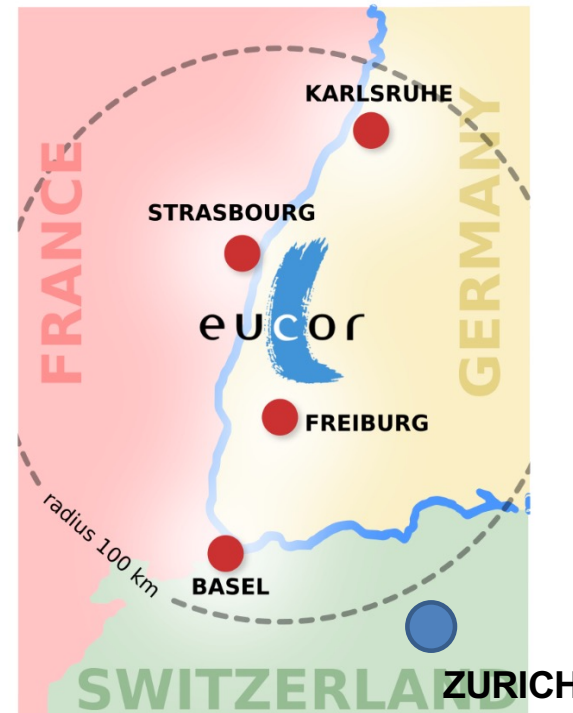
**A first-of-its-kind, international P...
program in quantum science and
technology (QST)**

**for 39 doctoral researchers across 3
countries 2020-2024**

→ **Strong QST Player in the Upper-
Rhine Region**

→ **Educating the Quantum Engineer
at**

- **University of Basel**
- **University of Freiburg**
- **Karlsruhe Institute of Technology**
- **University of Strasbourg**
- **Industry: IBM Zurich**



- ✓ Theory / experiments
- ✓ Solid state / Quantum optics
- ✓ Quantum dynamics
- ✓ Quantum technologies
- ✓ Quantum computing

First H2020 project to be approved to a
European Grouping of Territorial
Cooperation (EUCOR)

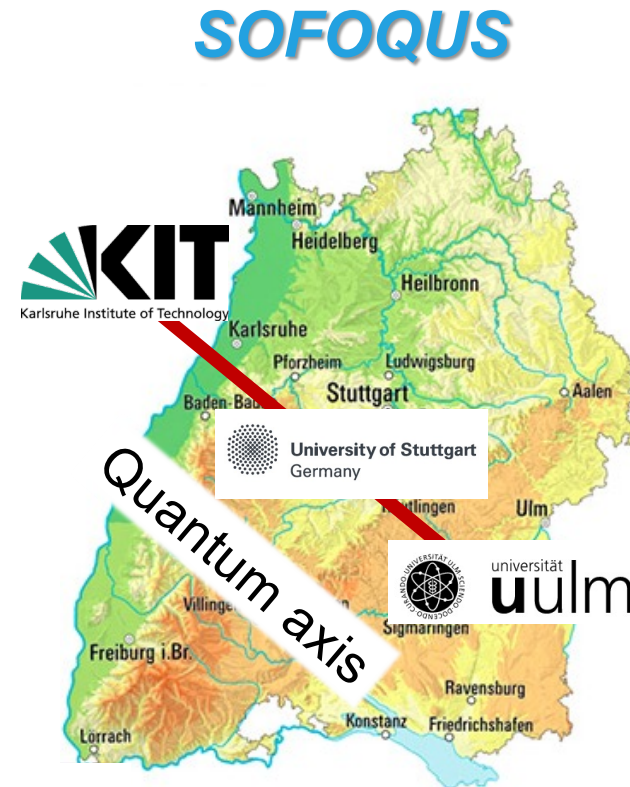
DFG Cluster of Excellence proposal: Self-organized functional quantum systems

Joint effort with Stuttgart and Ulm

- large number of joint QT projects ongoing
- previous interaction on SFB
- strong & complementary thematic fit

Central idea: Bottom up, self-organized quantum systems for quantum technologies

- **Area 1:** Self-organized quantum materials (molecules, color centers, ultra-cold atoms)
- **Area 2:** Engineered quantum properties (novel functionalities with integration in devices)
- **Area 3:** Application of emerging quantum functionalities (building blocks for quantum networks, distributed computing, sensing, simulation)





Enabling Cryo-Quantum Technologies

- Founded in early 2021 in Karlsruhe

Task:

“[...] development, production, worldwide distribution, and consulting of solutions in the field of cryogenics and quantum technologies.”

<https://qinu.de/>

Vision:

„Paving the way for everyday quantum technologies“

