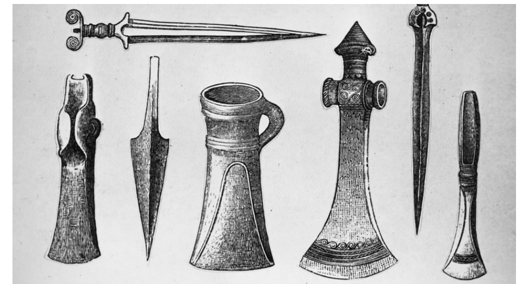
TECHNISCHE UNIVERSITÄT DRESDEN

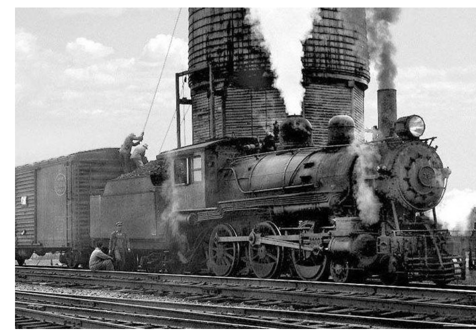
Vorstellung des Fortgeschrittenenpraktikums

Jochen Geck

IFMP
Institut für Festkörper- & Materialphysik

Materials and human history





Stone age | Bronze age | Iron age | Steel | Si

←2.5 Mio. B.C. | 3000 B.C. | 1200 B.C. | 100 B.C | 1950

Modern times

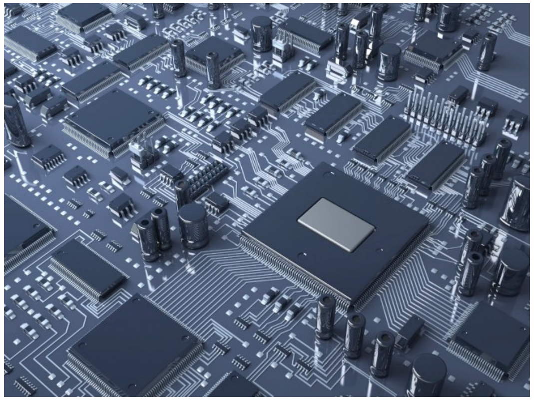
Materials in our society

buildings

transportation

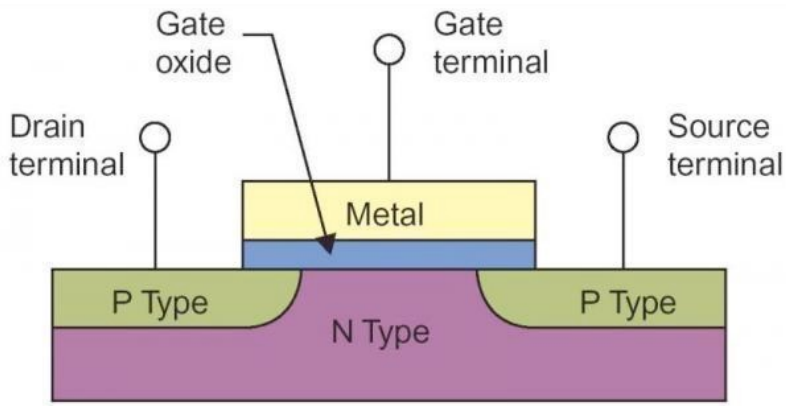
Energy generation, storage and transport

Information technology and electronics

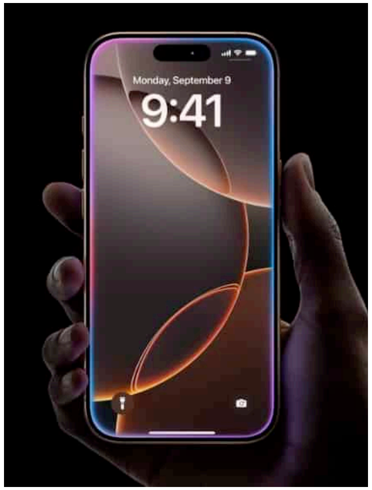


Consumer electronics

MOSFET: the electronic work horse



1980 1MHz, 64kB, 1820g



2024

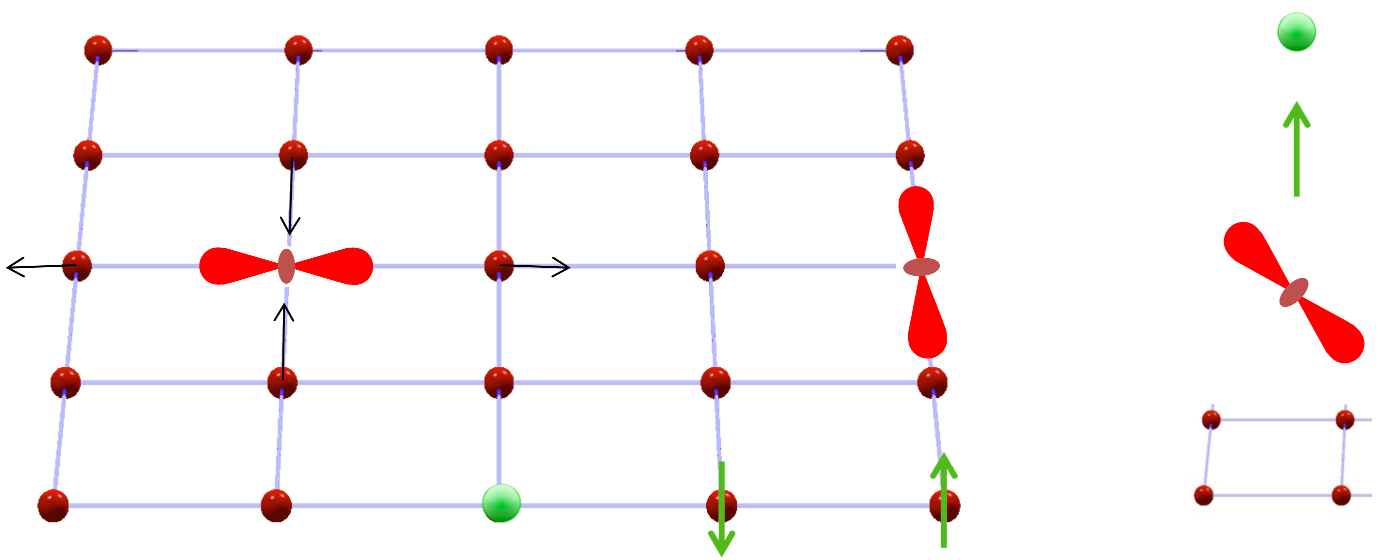
4 GHz
6 cores
1 TB
200g

Insulators, semiconductors, metals

- Enormous technological relevance
- Well understood electronic properties

Quantum materials

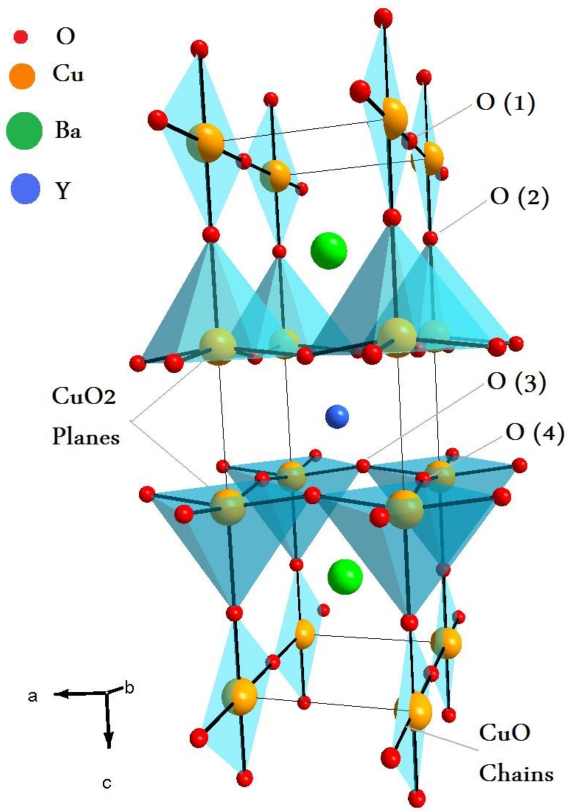
Various interacting degrees of freedom



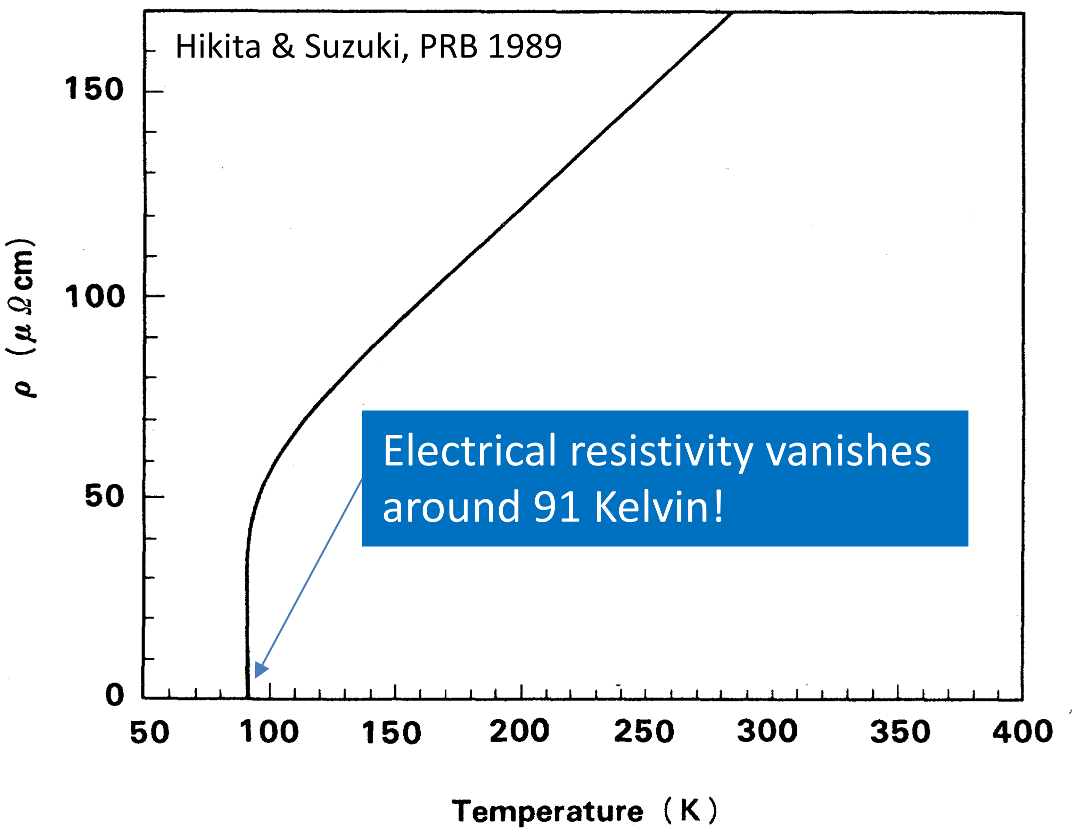
- Standard theories of condensed matter break down
- New electronic states of matter
- New types of (quasi-)particles!

High-temperature superconductivity

Famous example: $YBa_2Cu_3O_7$



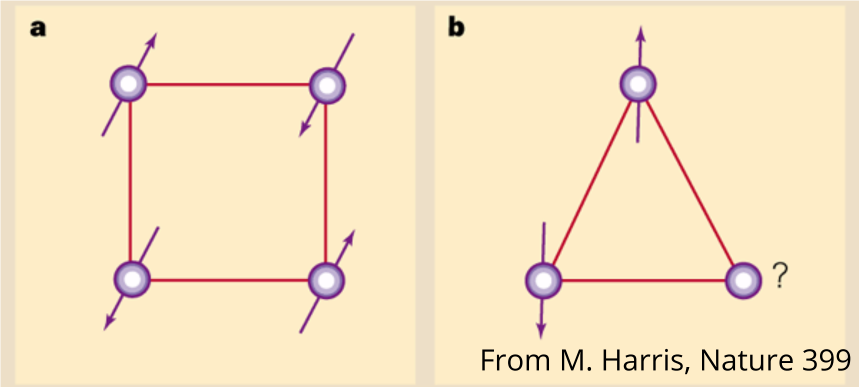
Electrical resistivity vs temperature



Mechanism of high-temperature superconductivity still not clear

Novel magnetic states of matter

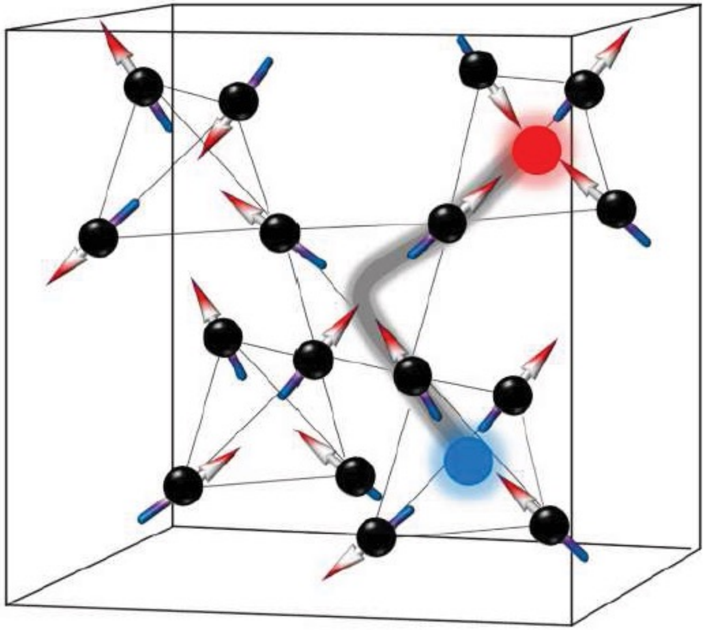
Geometric frustration of AFM-coupled spins

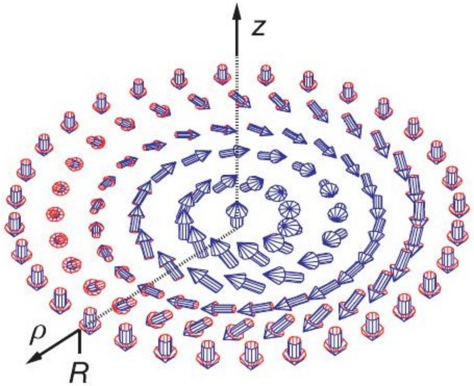


From M. Harris, Nature 399

Frustrated 3D lattice: spin ice

Examples: $Ho_2Ti_2O_7$, $Dy_2Ti_2O_7$





Fascinating and rich physics

- Magnetic monopoles
- **Quantum** spin liquids
- Fractionalization and confinement
- Majorana Fermions, Weyl Fermions, Anyons
- Skyrmions
- ....

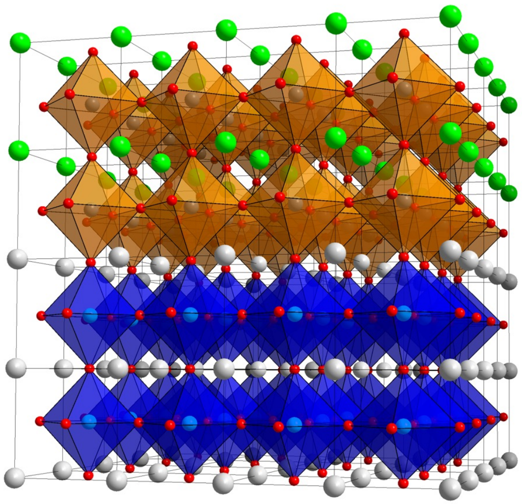
Condensed matter research

Basic science: “How does this work?”

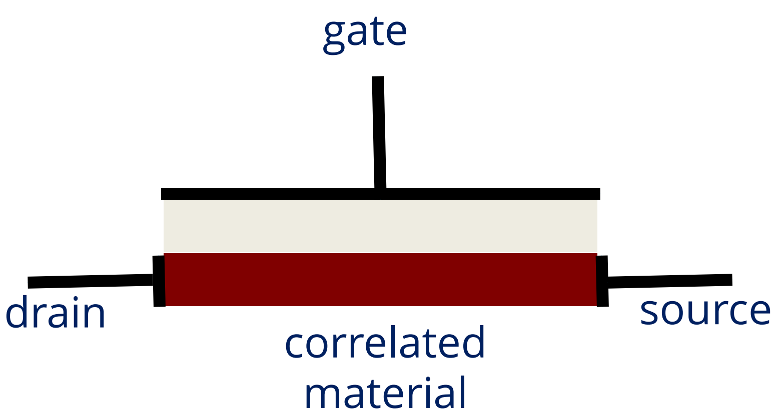
- Physics from the quantum over the mesoscopic to the macroscopic level
- Focus: materials with novel physical properties

Also: “Can this be useful?”

- Goldmine for new electronic phases
- Concepts for new technology



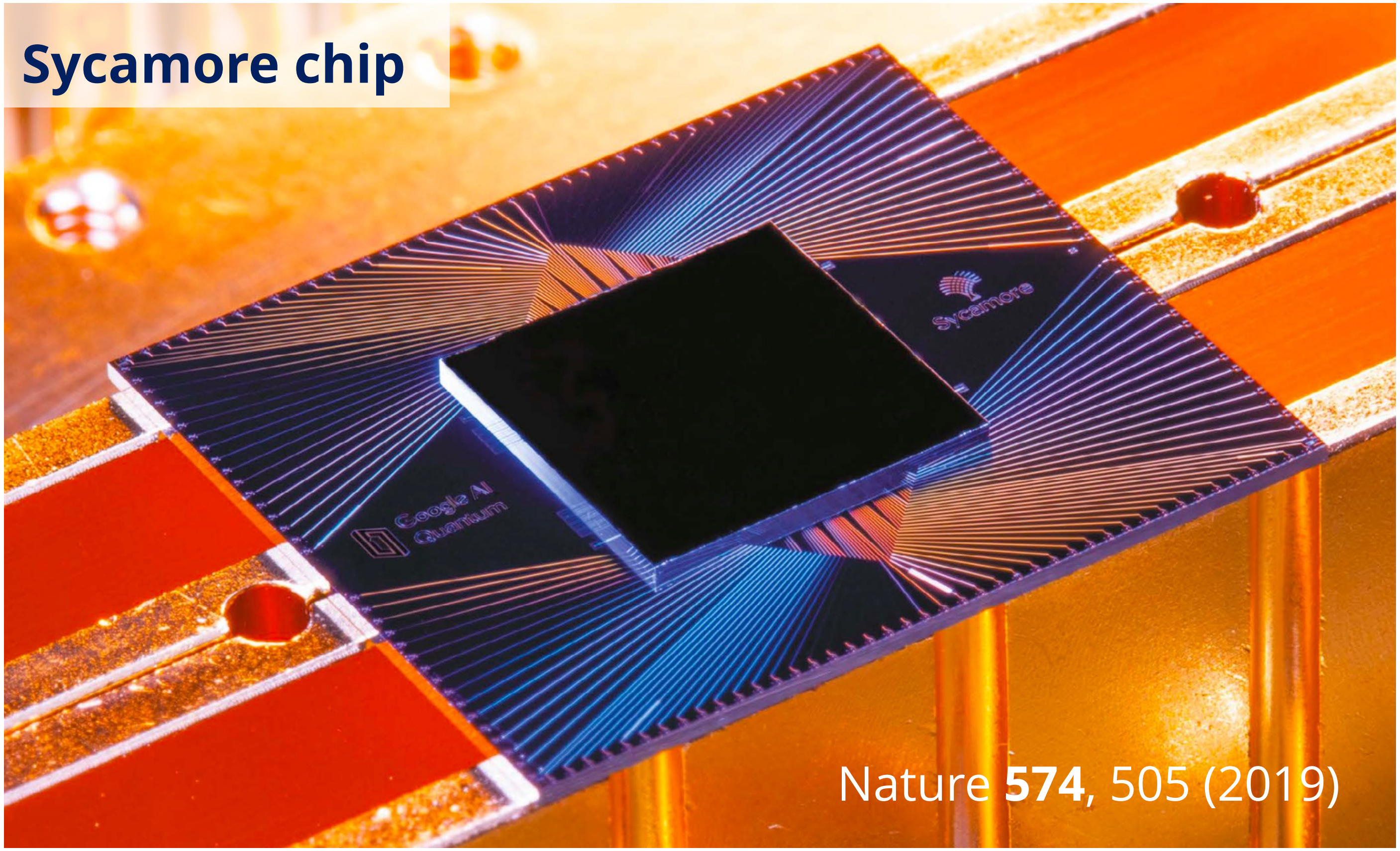
artificial heterostructures



MOTTFED

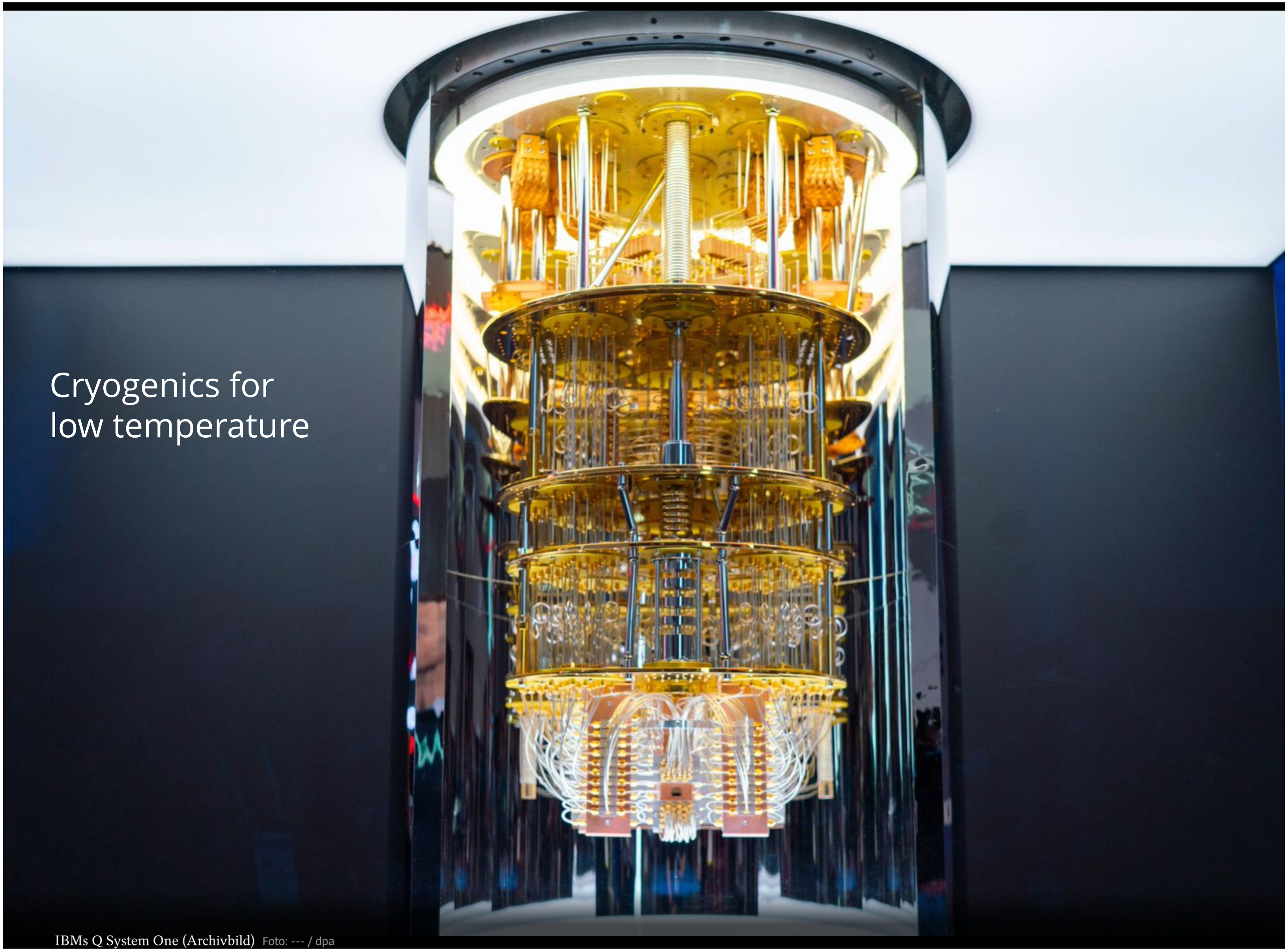
Googles Quantumcomputer

Oktober 2019: Publikation im Journal Nature



Chip mit **53 Quantum-Bits** (qbits) kann einen klassischen Supercomputer schlagen

IBM's Quantencomputer



Condensed matter in Dresden

Einer der führenden Standorte national & international

MAX-PLANCK-GESELLSCHAFT

TECHNISCHE UNIVERSITÄT DRESDEN

Leibniz Gemeinschaft

Fraunhofer

HELMHOLTZ

SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

Condensed matter in Dresden

Exzellenzcluster:

ct.qmat
Complexity and Topology in Quantum Matter

Sonderforschungsbereiche (**C**ollaborative **R**esearch **C**enters)

CRC 1143

Korrelierter Magnetismus:
Von Frustration zu Topologie

CRC 1415

Chemistry of synthetic two-dimensional materials

People

Institut für Festkörper- & Materialphysik

Prof. Jochen Geck	Physik der Quantenmaterialien
Prof. Elena Hassinger	Tieftemperaturphysik komplexer Elektronensysteme
Prof. Dmytro Inosov	Neutronenspektroskopie
Prof. Stefan Kaiser	Ultraschnelle Festkörperphysik und Photonik
Prof. Hans-Henning Klauss	Festkörperphysik/Elektronische Eigenschaften
Prof. Aparajita Singha	Nanoscale Quantum Materials

Prof. Bernd Büchner	Experimentelle Festkörperphysik
Prof. Axel Lubk	Elektronenoptik
Prof. Liu Hao Tjeng	Physik korrelierter Materie
Prof. Joachim Wosnitza	Physik in hohen Magnetfeldern
Prof. Jürgen Faßbender	Angewandte Festkörperphysik

What we do @ TUD

IFMP
Institut für Festkörper- & Materialphysik

Inosov:
Neutron-
scattering

Geck:
X-ray scattering,
spectroscopy

Klauss:
Nuclear probes

Kaiser:
Ultrafast
spectroscopy

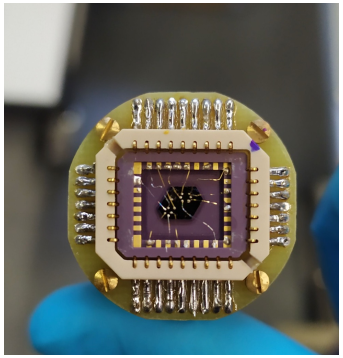
Hassinger
Thermodynamics
and transport

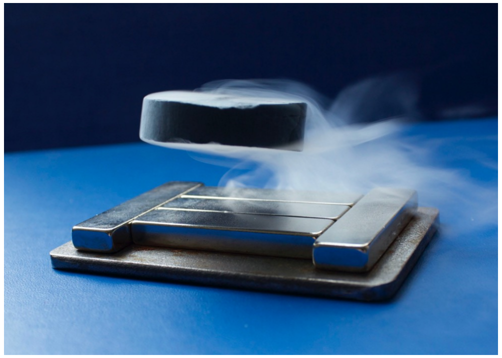
Singha:
Advanced
scanning probe
microscopy

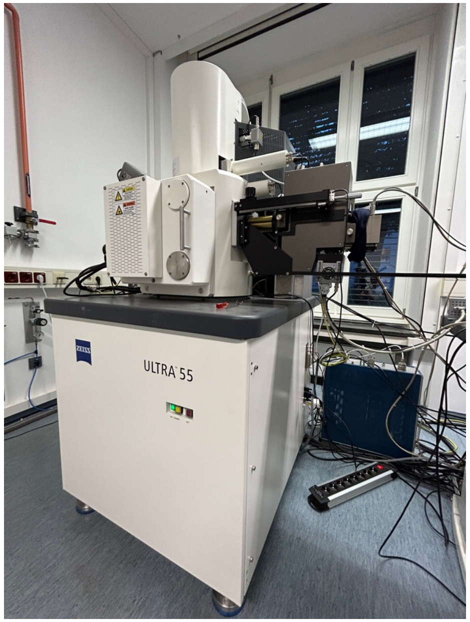
New material

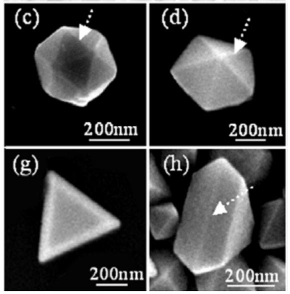
FP at IFMP

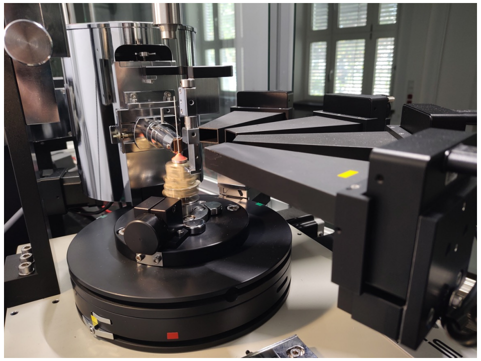
Macroscopic properties → **Nanoscale structures** → **Atomic scale**

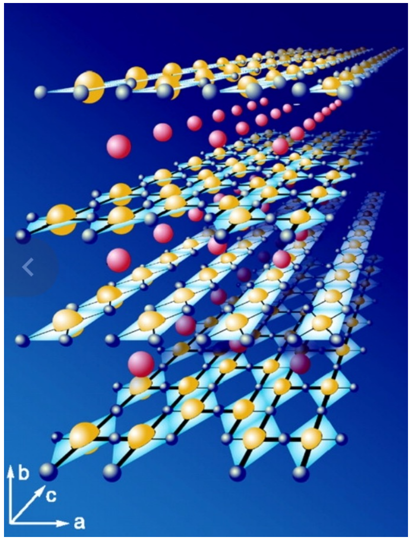












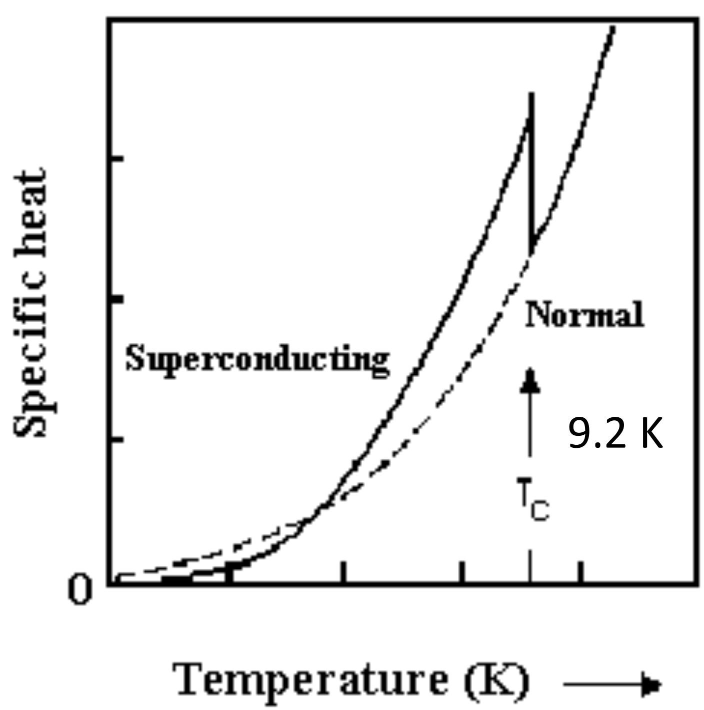
FP at IFMP: Examples

Thermodynamics

Macroscopic properties

Versuch: Phasenübergänge in Supraleitern (PSL)

- **Heat capacity of niobium between 4.2 K and 20 K**
- Different contributions: lattice (phonons) and electrons
- Metal to superconductor transition
- BCS theory of superconductivity
- Cryogenics with liquid helium



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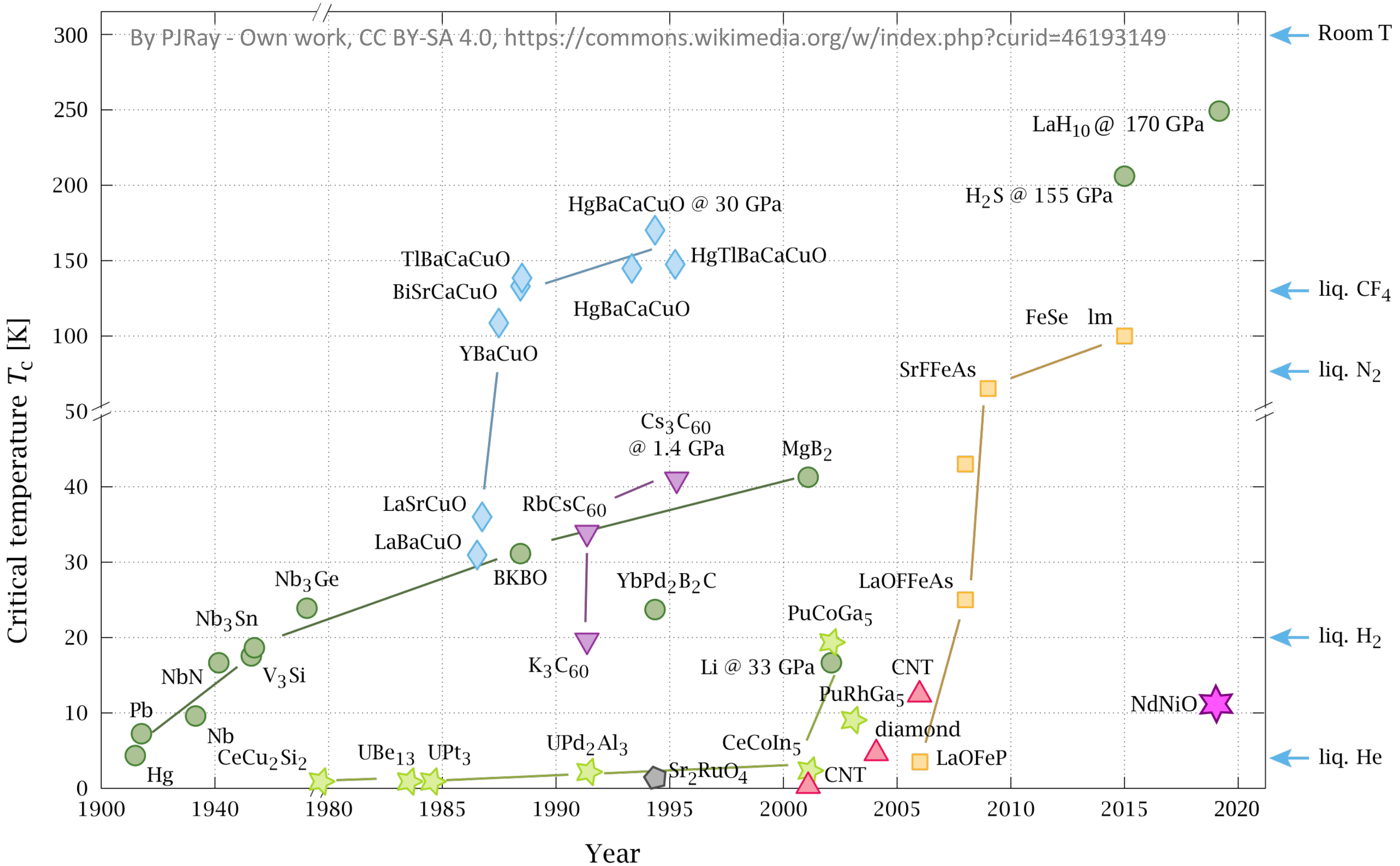
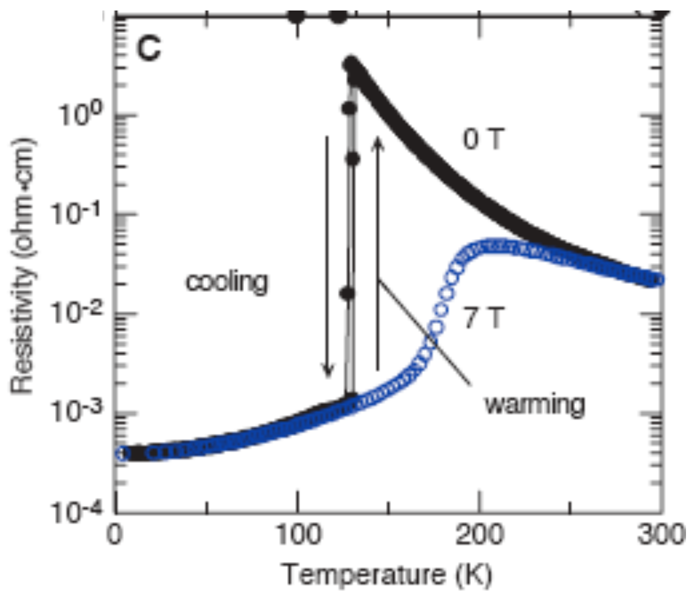


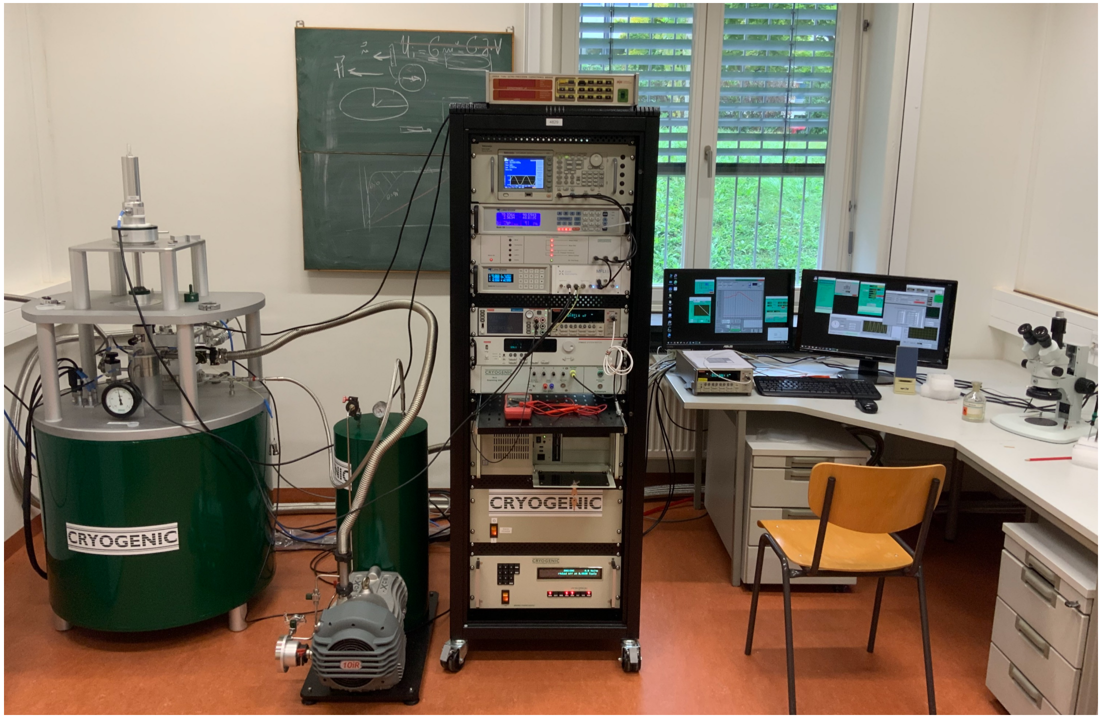
Versuch: Leitfähigkeit komplexer Oxide (LKO)

- **Charge transport in solids**
- Generation, measurement and control of low temperatures
- Colossal magneto resistance (CMR)
- Coupling of spin and charge
- Closed cycle cryostat

$Sm_{0.65}Sr_{0.45}MnO_3$



Tokura Science (2000)



FP at IFMP: Examples

Electron backscattering

at the scanning electron microscope

Nanoscale structures

Atomic scale

Versuch: Rückstreuelektronenbeugung (REB)

- **Scanning electron microscope studies**
- Key method for chemical and structural characterization on the nanoscale
- Topography, composition, crystalline orientation
- Focus: Electron Backscattering diffraction (EBS)

FP at IFMP: Examples

Nuclear probes in solid state physics

Atomic scale

Nanoscale structures

Versuch: Kernspinresonanz (NMR)

- Resonance technique: induced transitions between **different** $\boldsymbol{m_I}$ (I fixed)
- Energy levels of atomic nucleus changed by surrounding electrons
- Internal magnetic and electric fields
- Cryogenics (liquid helium)

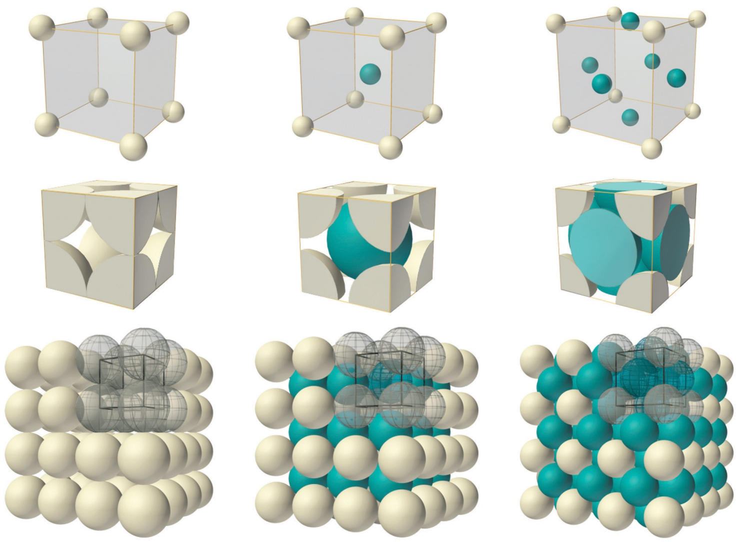
FP at IFMP: Examples

Atomic structure of solids

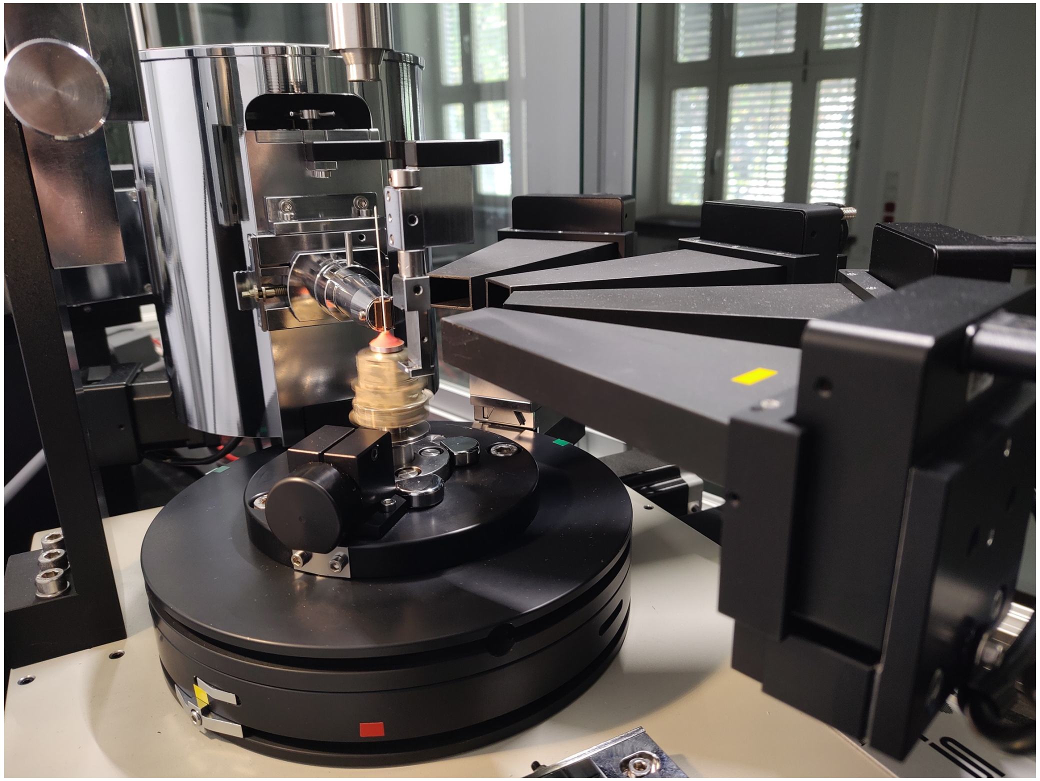
Atomic scale

Versuch: Röntgenstrukturanalyse (RS)

- **X-ray diffraction (XRD) of crystalline materials**
- Key method for structure determination
- Bragg's law, kinematical theory of XRD
- Selection rules and lattice symmetry (primitive, fcc, bcc)



(a) Simple cubic (b) Body-centered cubic (c) Face-centered cubic



Versuche am IFMP

Elektrische Leitfähigkeit von Festkörpern bei tiefen Temperaturen (am HZDR) (ELTT)

Ionenimplantation in Halbleiter (IH)

Leitfähigkeit komplexer Oxide (LKO)

Magneto-Widerstandseffekte in dünnen magnetischen Schichten (MR)

Mößbauerspektroskopie (MBS)

Nuclear Magnetic Resonance (NMR)

Phasenübergänge in Supraleitern (PSL)

Quantenanalogie (QA)

Rückstreuelektronenbeugung im REM (REB)

Röntgenstrukturanalyse (RS)

Supraleitung II (SU II)

Transmissionselektronenmikroskop (TEM)

Transversales Vibrationsmagnetometer (VSM)

Vakuumpraktikum 1 (VAK1 / Vakuumerzeugung)

Vakuumpraktikum 2 (VAK2 / Vakuummesstechnik)

Vakuumpraktikum 3 (VAK3 / Gaskinetik und Strömungen)

Atomare Struktur

Elektronischer Transport

Magnetismus

Thermodynamik

Techniken

Summary

- All the way down from the **macroscopic to the atomic scale!**
- You learn about key experimental methods of modern condensed matter science
- Geometric structure, electronic structure, thermodynamics, magnetism…

Thank you very much for your attention!