SOLID STATE PHYSICS III

Fall Semester 2024
PHYS-419

Andreas Läuchli
LLTCP @ EPFL & LTC @ PSI

Pratyay Ghosh
CTMC @ EPFL

Tianyue Huang
LLTCP @ EPFL

ORGANISATION

- Lectures (Andreas Läuchli) on
  Wednesday 13:15-14:00 GR A3 32
- Exercises (Pratyay Ghosh and Tianyue Huang) on
  Thursday 08:15-10:00 in GR A3 32
- There is a Moodle page, with upcoming slides, supporting material, and the exercise sheets.
- There might be lecture notes in the end, but lecture notes by others will be made available when we rely on them
- 1) Assessment of a subset of the exercise sheets handed in
- 2) Oral examination: ~20-30 minutes session on the blackboard

YOUR BACKGROUND ?

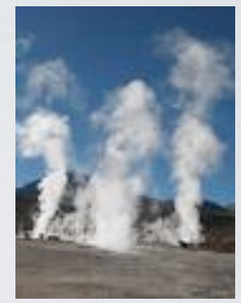
- This is a MA1 lecture, with people from a range of backgrounds (EPFL bachelor or incoming) or study programs.

- Solid State Physics I+II / Topological Insulators ?
- Statistical Physics / Phase Transitions / Second Quantization?
- Quantum Information in parallel ?
- Quantum Field Theory in parallel ?

OUTLINE

- What is "Solid State Physics (III)"?
- Planned Content:
  - Band Theory, Excitons, Interaction effects in metals
  - Metals in magnetic field, Quantum Hall effects
  - Superconductivity
  - Mott Insulators, Quantum Magnetism
- Focus is on phenomena and thorough qualitative understanding.
- Exercises will consist both of analytical and numerical problems.

INTRODUCTION



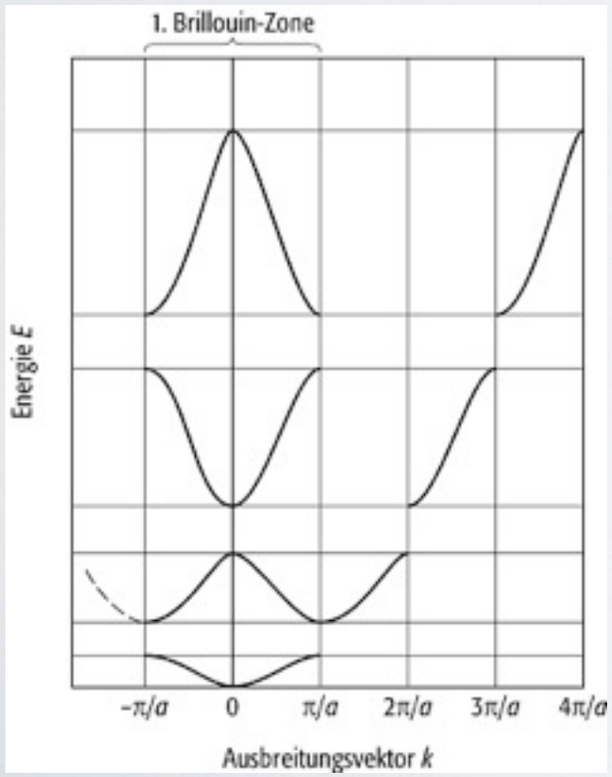
$$H = \sum_i -\frac{\hbar^2}{2m_i}\Delta_i + \sum_{i,j}\frac{e_i e_j}{|\mathbf{r}_i - \mathbf{r}_j|}$$

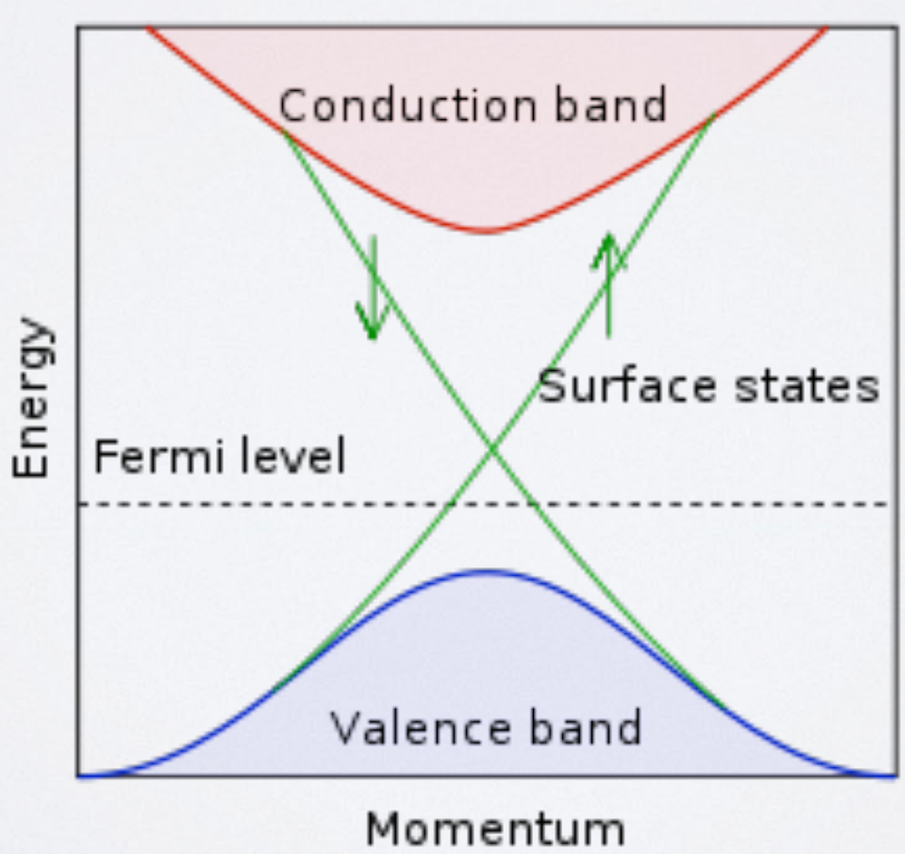
- The "Theory of everything" is basically known in solid state physics / condensed matter
- Despite the known TOE it is challenging to predict all the possibilities and phenomena arising out of the Schrödinger equation, with constantly new surprises
- Emergence: "More is different" P.W. Anderson, Science 1972

BAND STRUCTURES

- Band structure an important concept from early days of quantum mechanics. Lets us differentiate between metals and insulators (semiconductors)

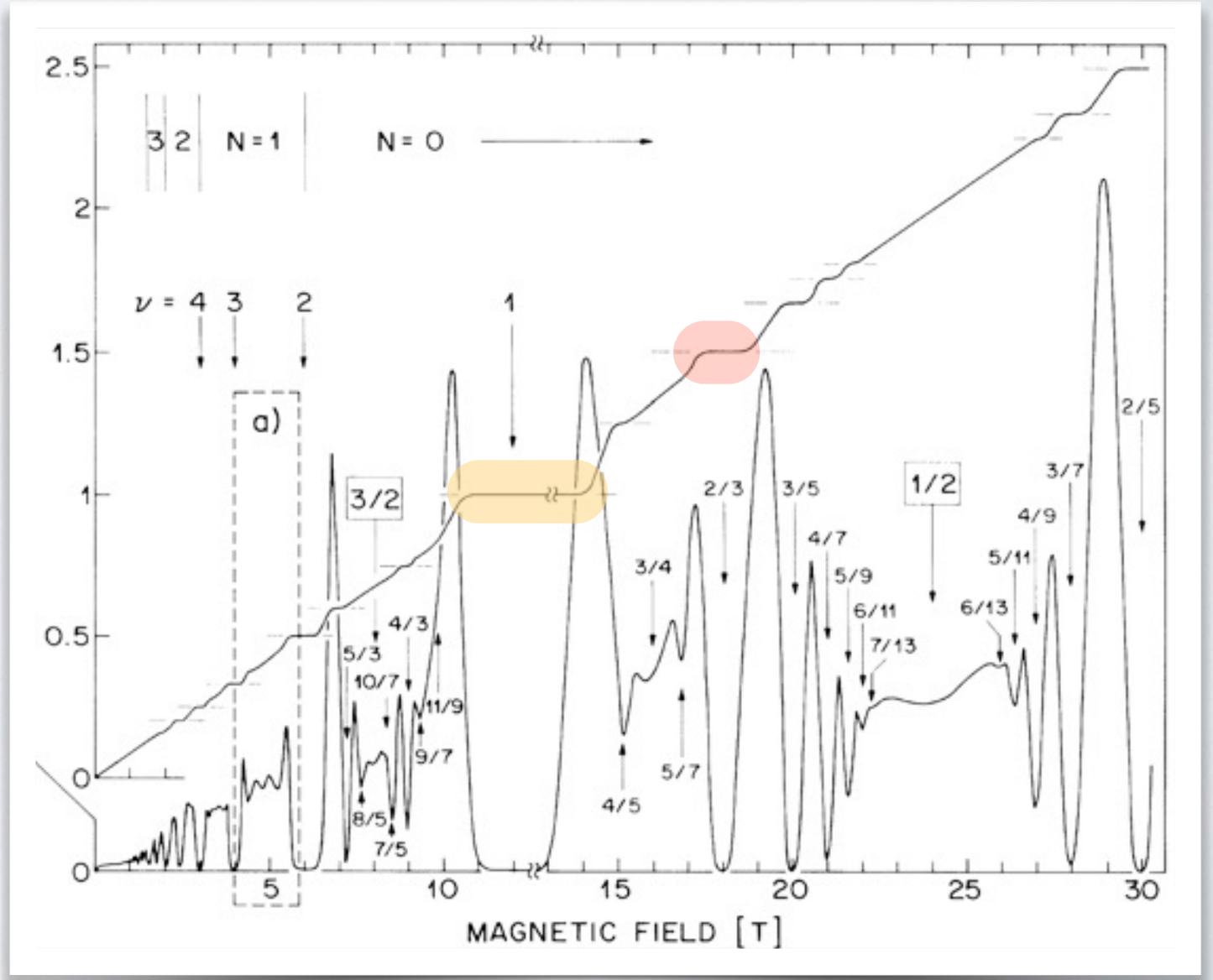
- Only known since about 20 years
  normale band insulators ≠ topologic insulators





METALS AND MAGNETIC FIELDS

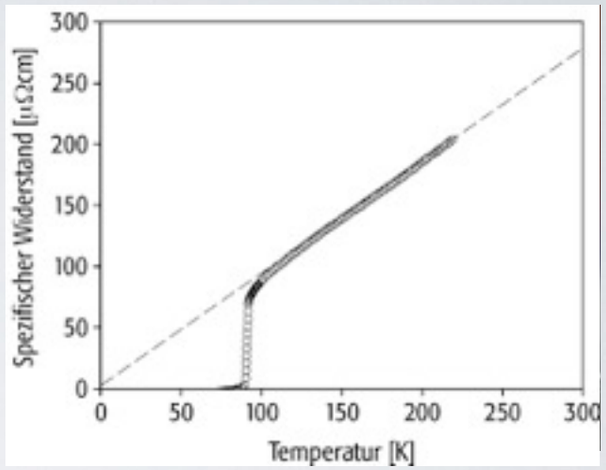
- De Haas van Alphen effect, Landau Levels
- (Fractional) Quantum Hall effect,
  - Anyons (FQH)
  - Nonabelian Anyons ? QC ?



1985/1998/2016

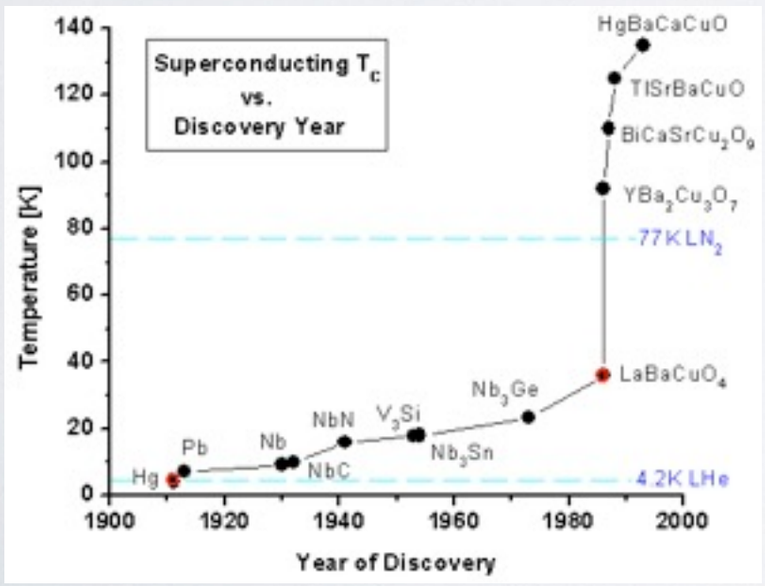
SUPERCONDUCTIVITY

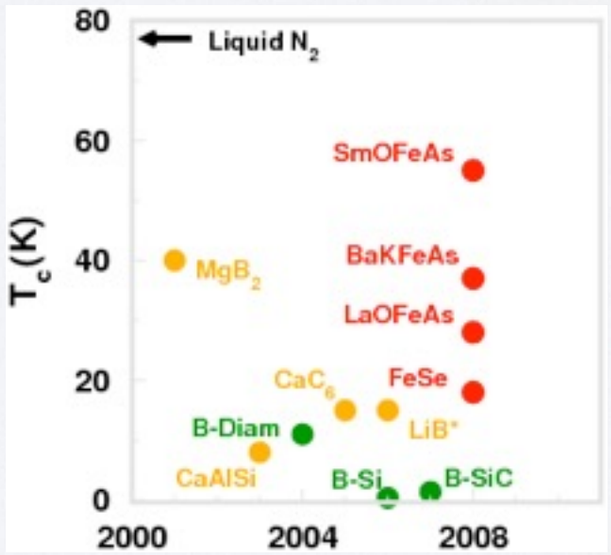
- Abrupt loss of resistivity
  expulsion of magnetic flux from material

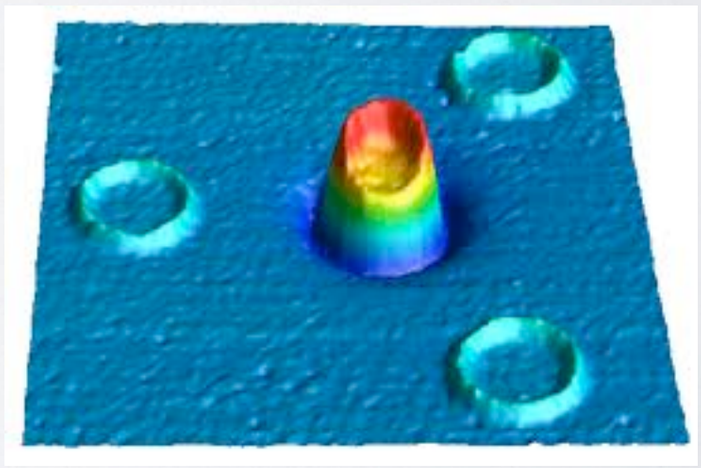


- Long time between discovery (1911)
  and explanation: BCS (1957)

- Phonons, electron-electron interaction
  exotic pairing properties

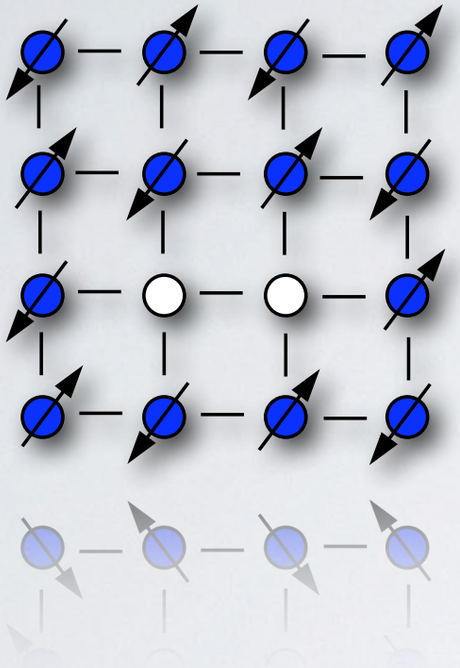


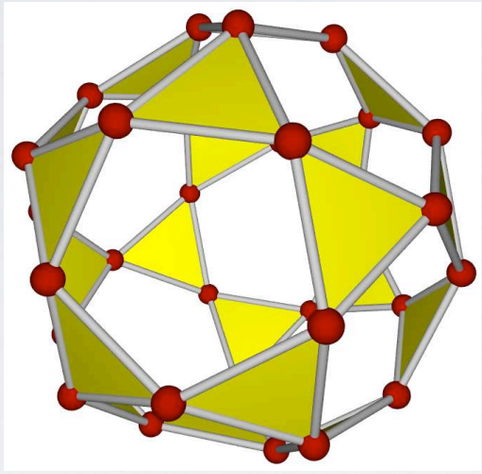


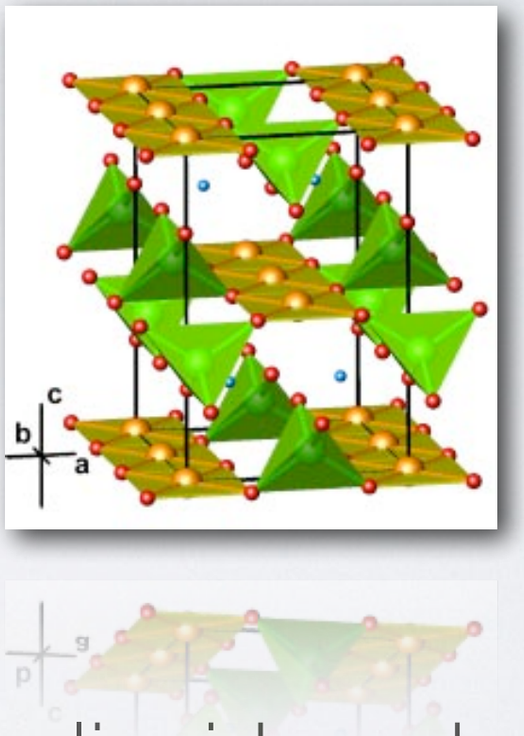


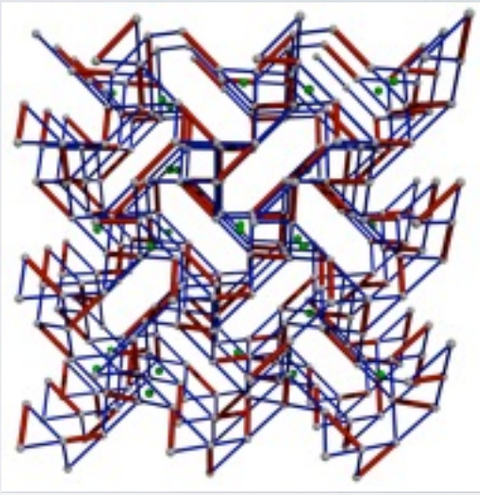
many ! 1913/1962/1972/1973/1987/2003

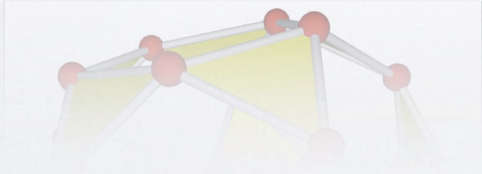
MOTT INSULATORS



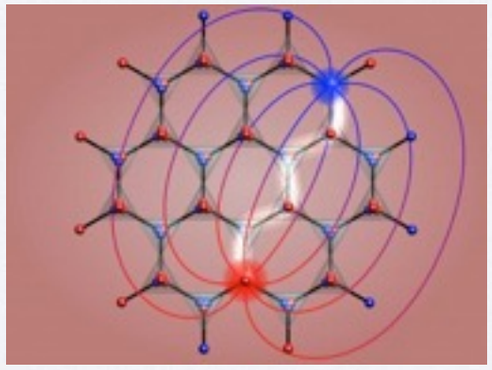




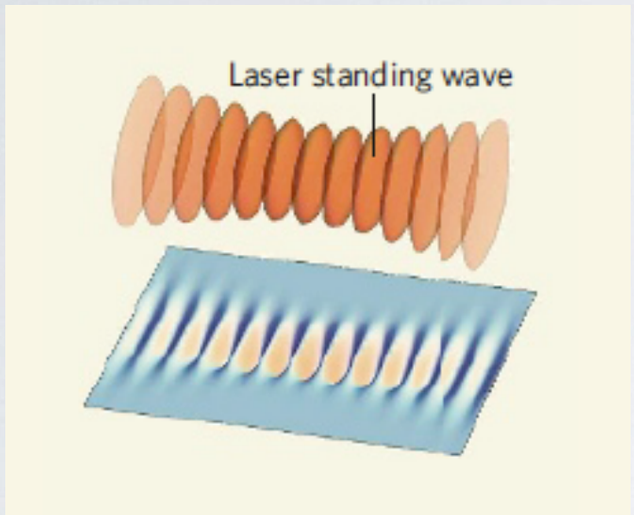


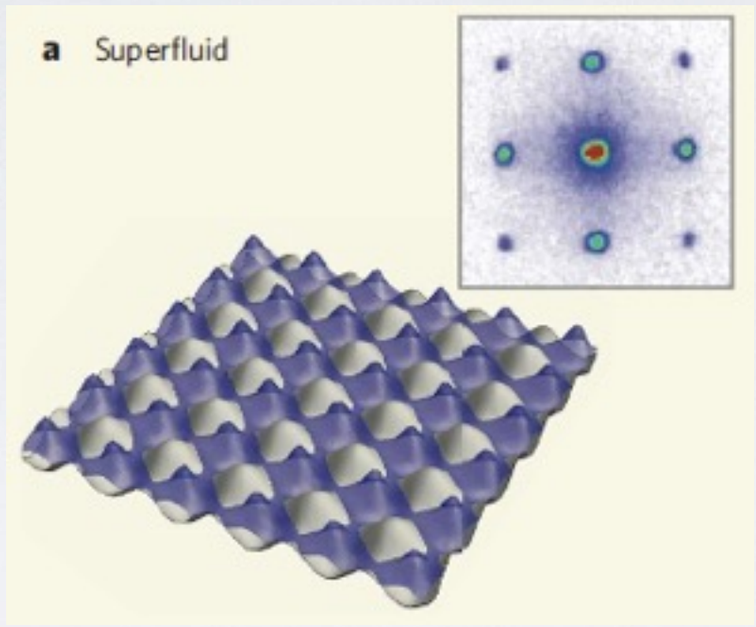


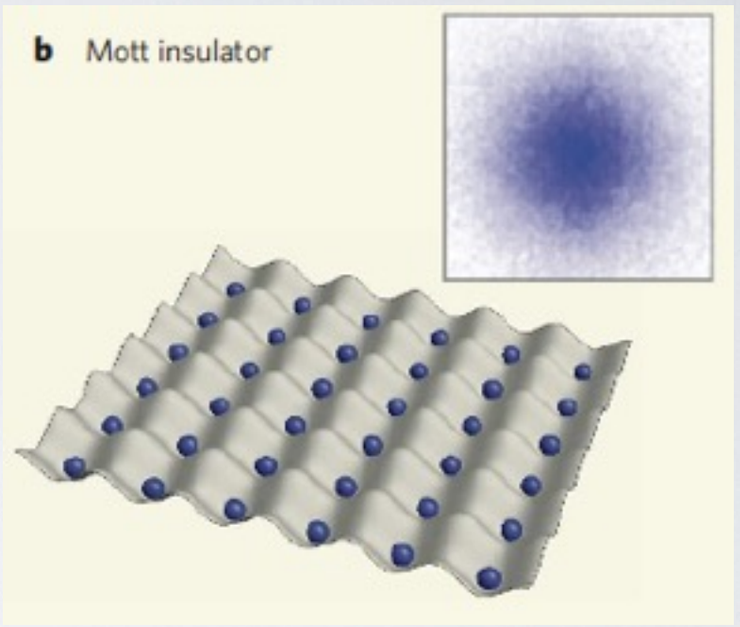
- From "classic" magnetism to spin liquids and effective lattice gauge theories and magnetic monopoles



COLD ATOMS ⇔ COND-MAT







- Cold atoms in optical lattices or tweezers
- Many body physics with phenomena similar to Condensed Matter
- Quantum simulators / Interesting systems in their own right

IMPORTANT CONCEPTS

- Universe in a "spin chain" / "It from Qubit"

- For condensed matter systems: quantum magnets, metals, superconductors, fractional quantum Hall systems, …

- For synthetic quantum systems: quantum simulators, quantum computers, different platforms: atoms, ions, superconducting qubits, photons,…

- For high energy physics: black hole information puzzle, "it from qubit", lattice gauge theories

- For quantum field theory, statistical physics, quantum information

- For numerical methods: e.g. tensor network methods