Magnetism in Strongly Correlated Electron Systems

Correlated Quantum Matter Group, Prof. Marc Janoschek

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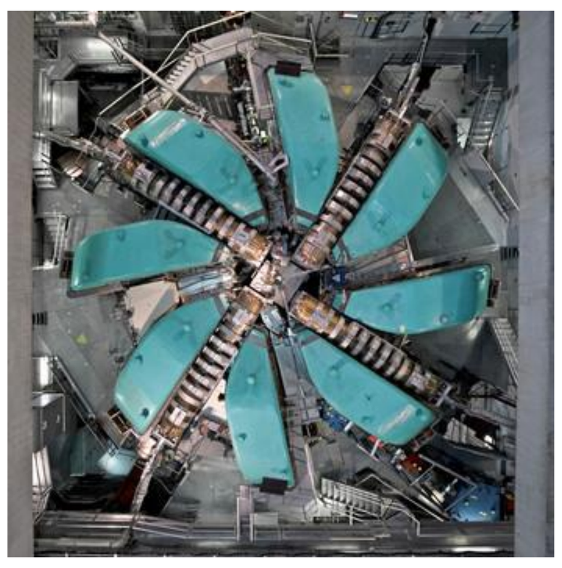
What we do

Our group investigates magnetic quantum matter states in strongly correlated electron systems. We study these correlated quantum phases by means of neutron and X-ray scattering, nuclear magnetic resonance (NMR) and various bulk measurements (electrical transport, magnetization, specific heat, ultrasound). Quantum matter is defined as any state that exhibits macroscopic properties driven by dominant quantum interactions. Quantum matter states are already used in current day applications but many recently discovered states in the fields of magnetism, superconductivity and novel quantum matter states are promising for future applications.

Where we are

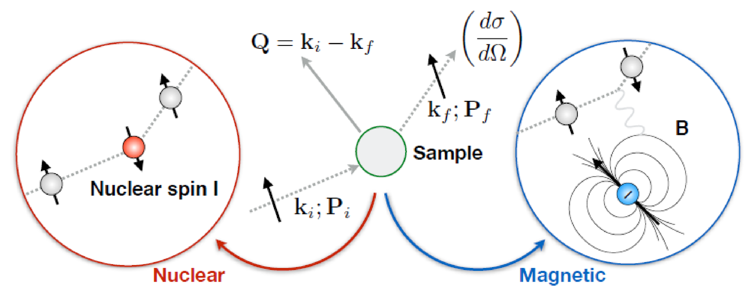
Our group is located at the Paul Scherrer Institute (PSI) and associated with the Swiss neutron spallation source SINQ.

SINQ

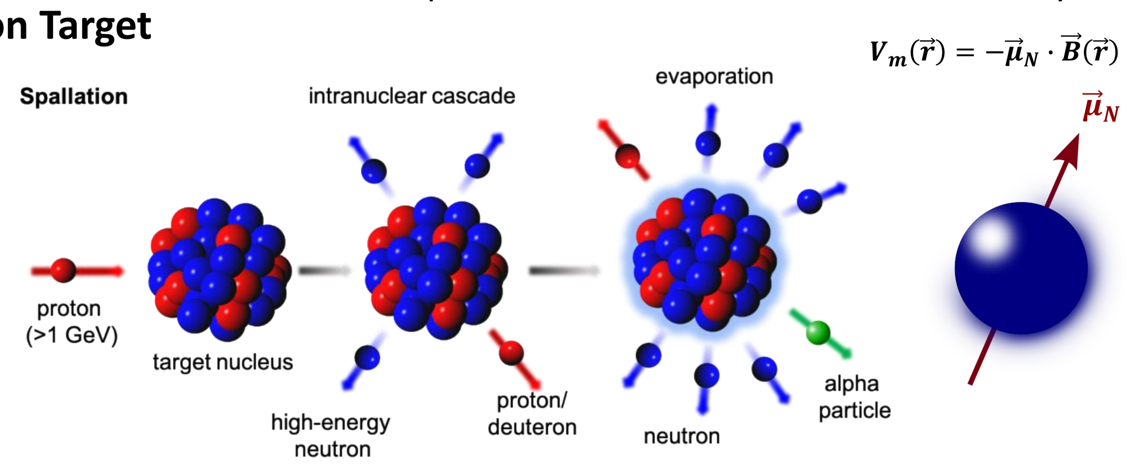


Proton Accelerator **Spallation Target**

The High Intensity Proton Accelerator (HIPA) accelerates protons to a kinetic energy of 590 MeV (60% of speed of light). The main proton cyclotron shown above has a diameter of nearly 20 m, and remains the most powerful continuous wave proton accelerator. The protons hit a neutron target consisting of lead, and generate spallation neutrons. The produced neutrons are than moderated to thermal (25 meV) and lower energies corresponding to wavelengths suitable for neutron scattering experiments (~ Å)



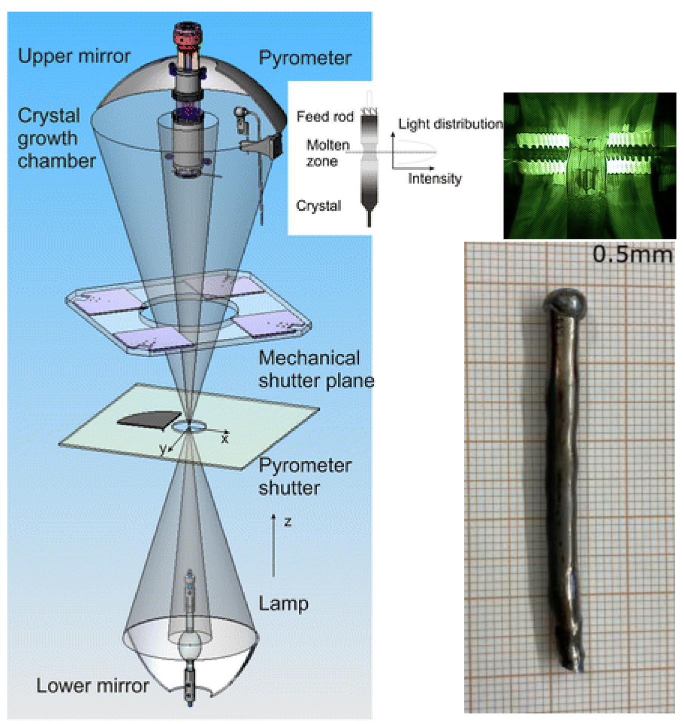
Neutrons are probes of structural and magnetic information, as they couple both to nuclei and magnetic moments. Neutrons possess a magnetic dipole moment which makes them sensitive to magnetic fields generated by unpaired electrons in the materials we study.



Making Samples

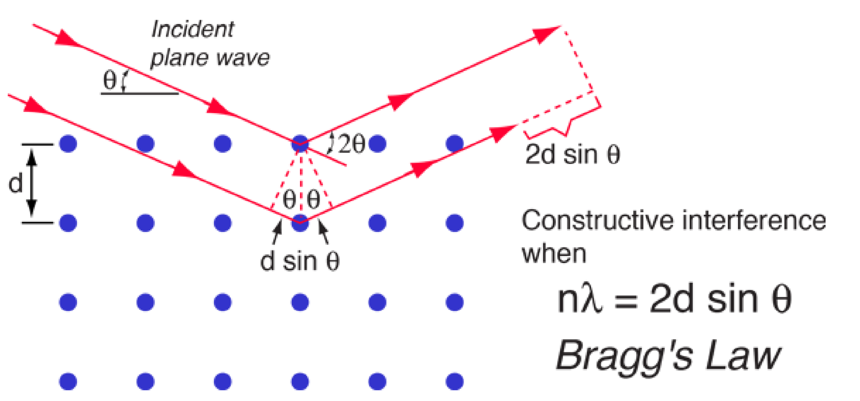
Working with collaborators at PSI, we grow materials with underlying properties and symmetries that support the formation of quantum matter states.

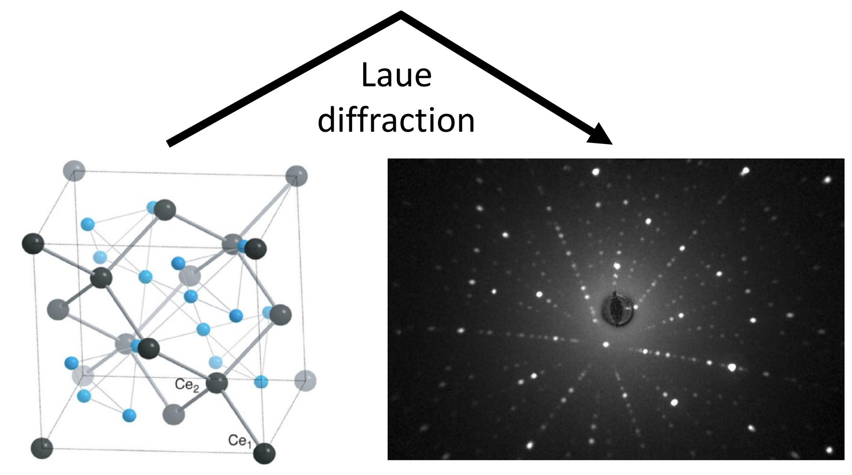
Depending on the material's growth conditions and the required sample mass, the most promising growth technique will be chosen.



A commonly used technique is the traveling floating zone method, where a molten zone created from focused light travels vertically along a feed rod creating a single crystal on top of a seed rod.

The quality and orientation of the grown crystals can be determined by a X-ray diffractometer that is based on Bragg's law.

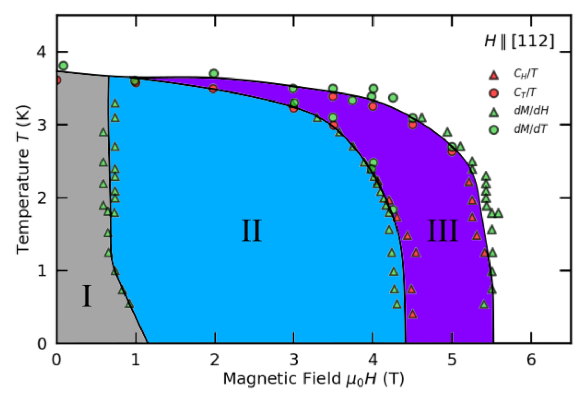


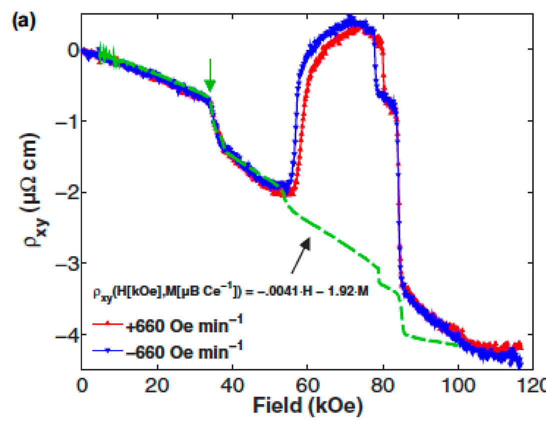


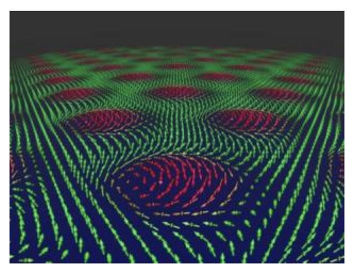
Crystal structure (real space) — Laue picture (reciprocal space)

Magnetic Phases and Properties

From transport, physical and magnetic property measurements we can determine the magnetic phase diagram of a system and get information about magnetic and electronic properties.

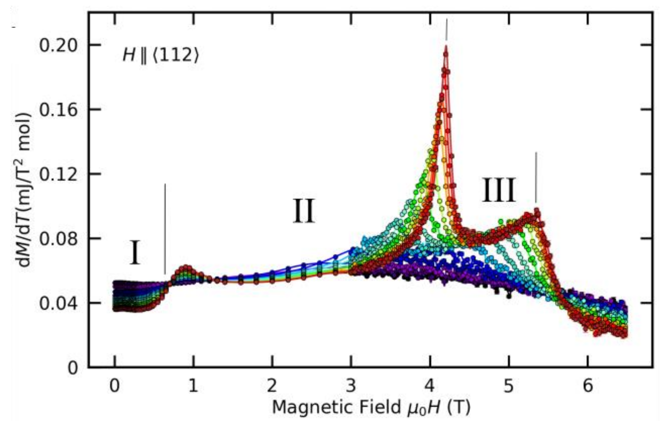




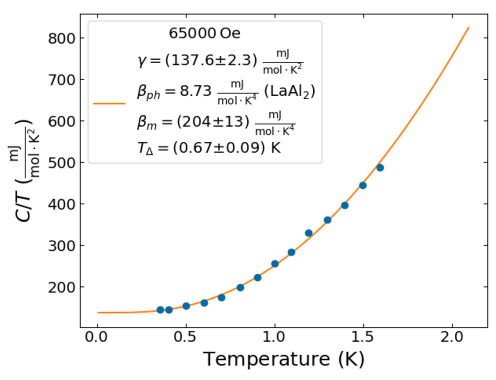


$N_{Sk} = \frac{1}{4\pi}\int d^2 r \boldsymbol{M}\cdot\left(\frac{\partial \boldsymbol{M}}{\partial x}\times\frac{\partial \boldsymbol{M}}{\partial y}\right)$

Skyrmions are topological objects that have a topological charge $N_{Sk} = -1/(\text{unit cell})$ resulting in a topological contribution to the anomalous Hall effect.



Using specific heat, magnetic susceptibility, electrical resistivity, as well as neutron diffraction, we can determine the phase boundaries.

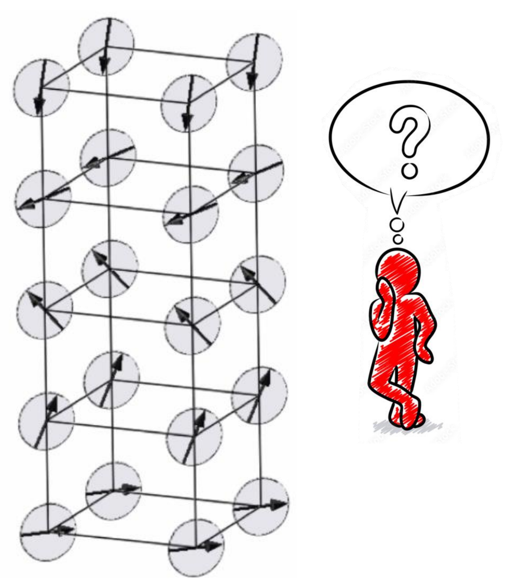


Specific heat contains electronic, lattice and magnetic contributions. By fitting recorded data, the strength of the different contributions for the specific compounds can be evaluated.

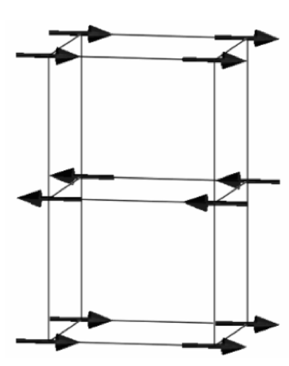
$$\frac{C(T)}{T} = \gamma + \beta_{ph}T^2 + \beta_m T^2 e^{-T_\Delta/T}$$

Magnetic Structure

Using neutron diffraction, we determine the magnetic structure of a compound, within the specific magnetic phases.



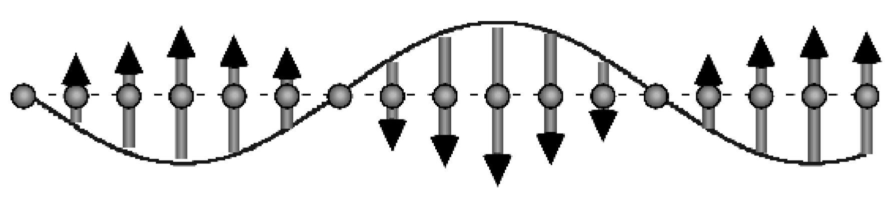
Simple structures



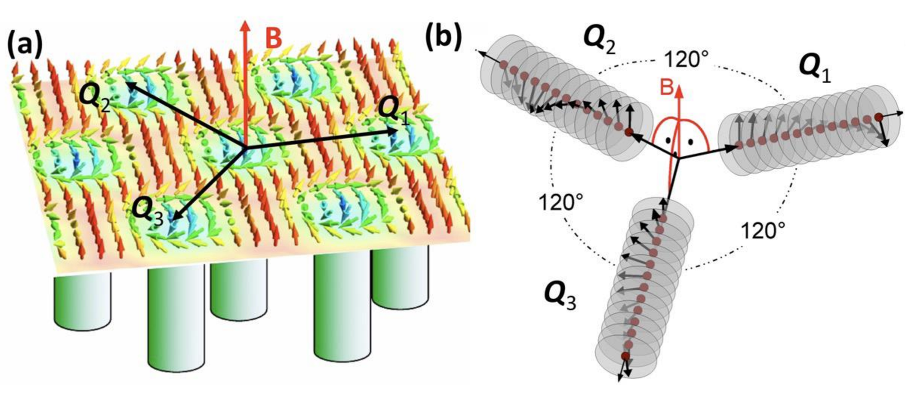
Collinear antiferromagnet

Complex structures

- Modulated structures



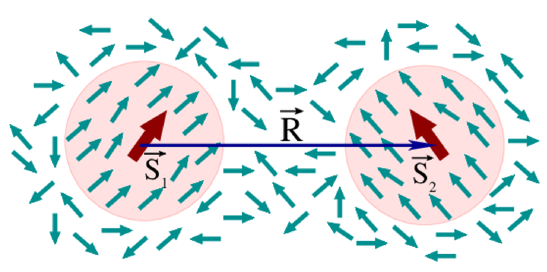
- Topological structures (e.g. magnetic Skyrmions)



- Absence of magnetic order as in spin liquids

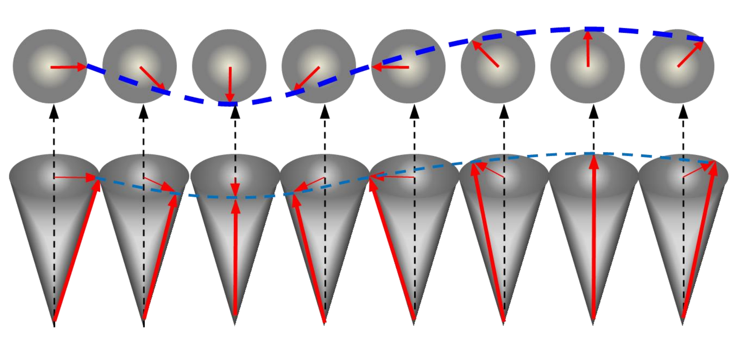
Magnetic Interactions

Using neutron spectroscopy we measure the spin wave excitations of magnetically ordered systems to determine the microscopic magnetic interactions.



We want to understand the interactions between the different magnetic moments.

Spin wave excitations (magnons)



Collective excitations with bosonic character.

Together with our theory collaborators we develop models that we compare to the measured magnon dispersion to get out the interaction parameters.

Neutron spectrometer CAMEA located at PSI.