PSI Center for Neutron and Muon Sciences

Universität Zürich UZH

Probing Atomic Scale Structures and Interactions in Quantum Matter

M. Islam[1], J. Philippe[1,2], G. Simutis[1], M. Bartkowiak[1], M. Janoschek[1,2]

[1] PSI Center for Neutron and Muon Sciences, CH-5232 Villigen PSI, Switzerland

[2] University of Zürich, Correlated Quantum Matter, CH-8057 Zürich, Switzerland

[3] University of Zürich, Physics Institute, CH-8057 Zürich, Switzerland

Correlated Quantum Matter Group

Who are we and what do we do?

The ***Correlated Quantum Matter group*** is jointly funded by UZH and PSI, where it is part of the Laboratory for Neutron and Muon Instrumentation (LIN).

Research topics

- The overarching theme of our research are **quantum phenomena** that arise in bulk materials governed by **collective electronic behaviour.**
- Electronic correlations couple spin, charge and lattice degrees of freedom, producing emergent and rich low-energy physics.
- Examples of these phenomena include quantum spin liquids, skyrmion lattices and novel superconductors.
- We tune properties of quantum materials to establish their functionality for possible future applications from quantum computation to novel versatile sensors and electronics.

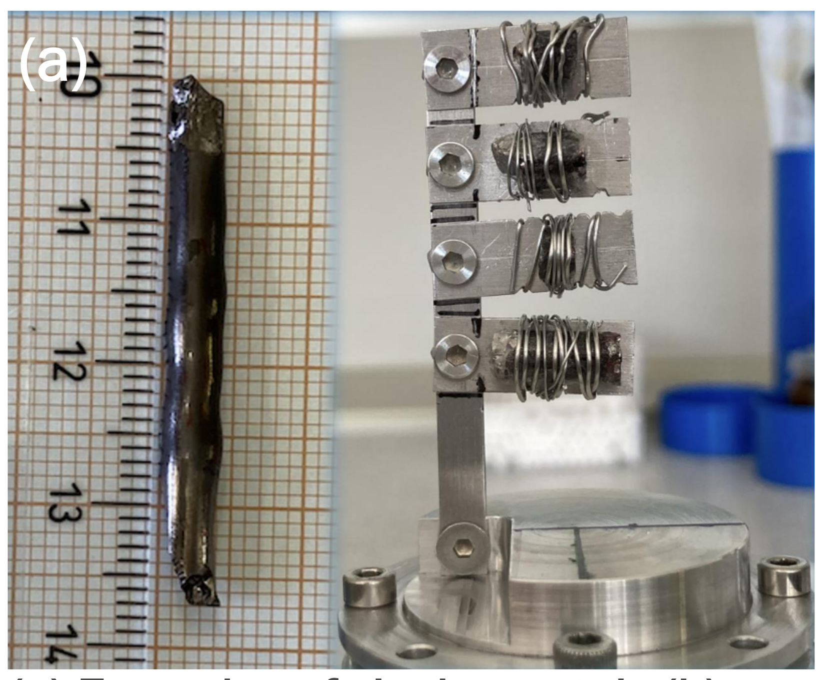
How do we do this?

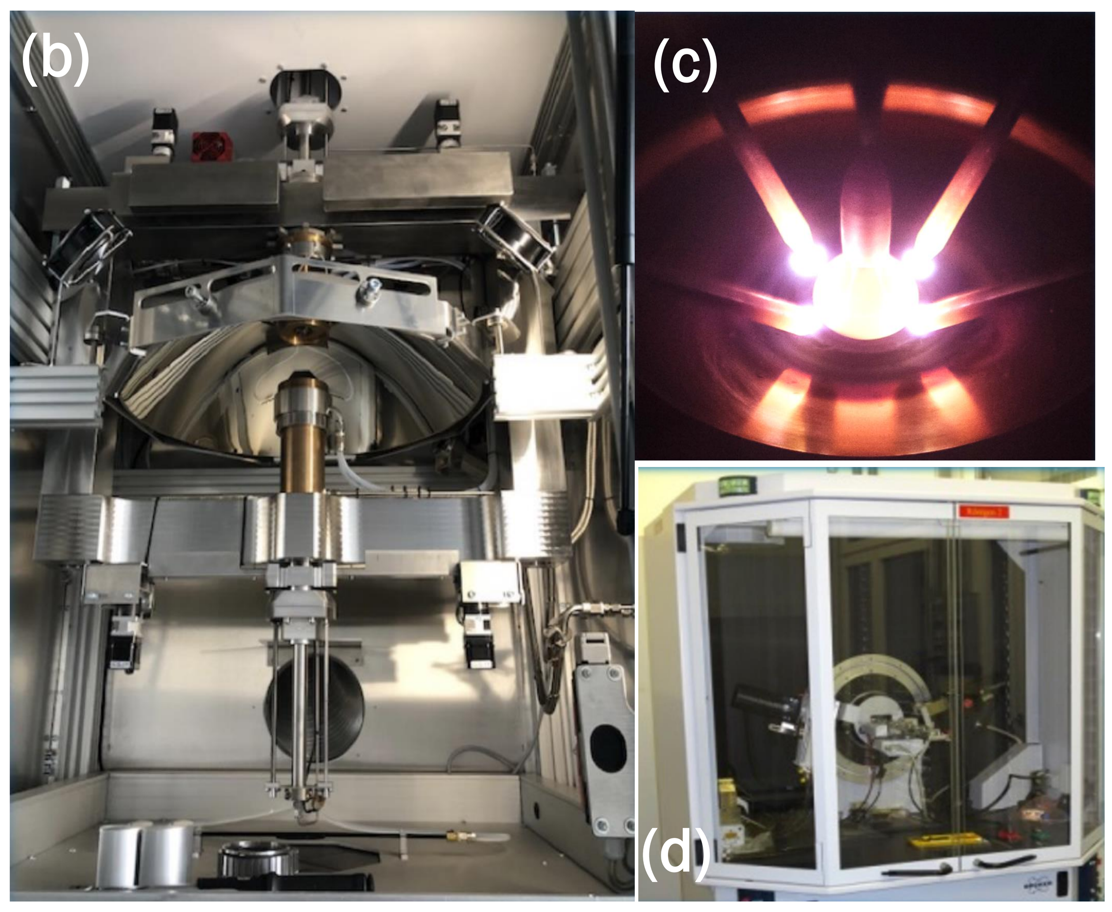
- We learn how to tune underlying quantum interactions via external parameters such as pressure, field, strain and crystal chemistry.
- We control and optimise properties of quantum materials via these parameters.
- To do this, we use state of the spectroscopy at large-scale neutron, photon and muon facilities

Making Quantum Materials

Motivation: High quality quantum materials for study

- We aim to find not only good candidates exhibiting these exotic quantum phenomena but also grow and produce high quality **single crystal samples** of sufficient size (see (a)) for **magnetic property** and **neutron scattering measurements.**
- Growth techniques include: (b) Floating zone method (c) Czochralski single crystal growth and sample quality is checked via (d) X-ray diffraction.



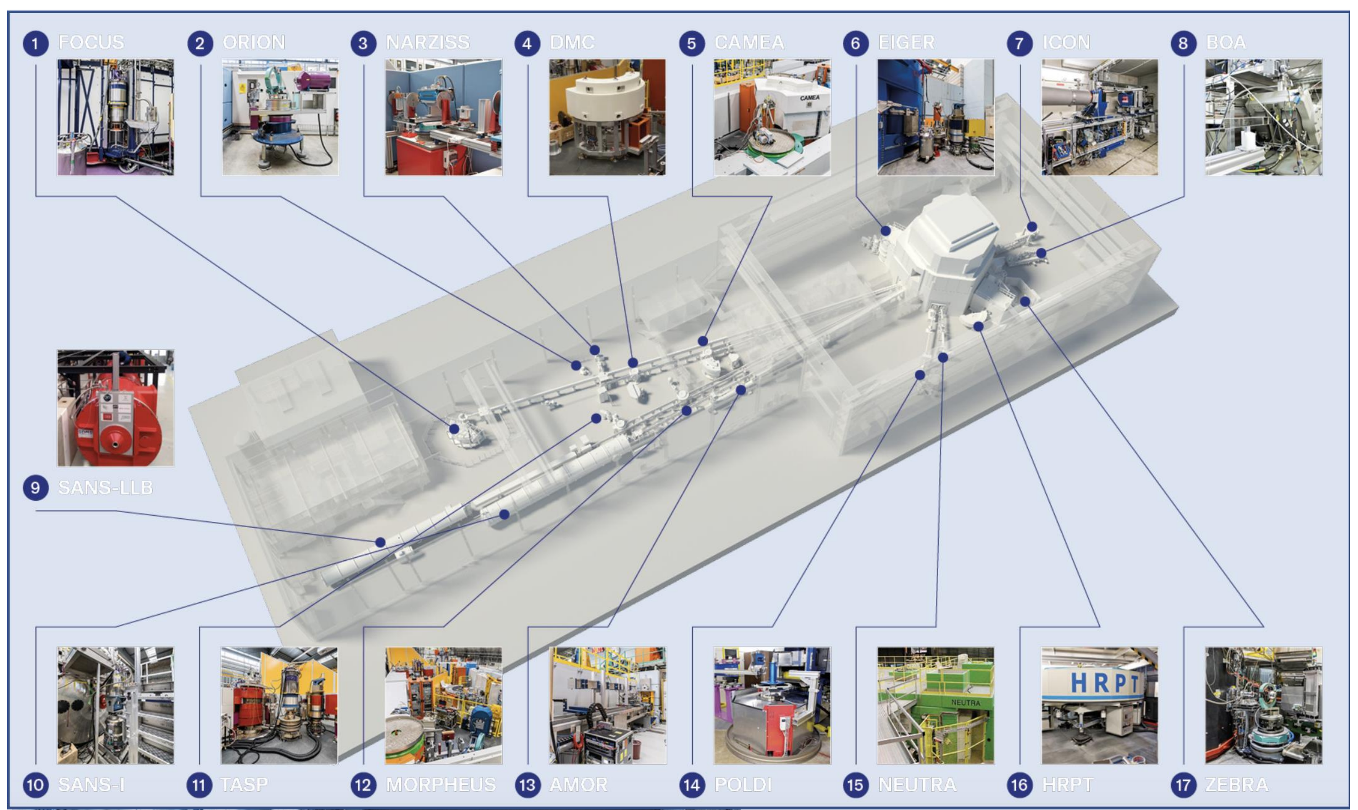


(a) Examples of single crystals (b) High pressure floating zone furnace (c) Czochralski single crystal growth (d) X-ray diffractometer

Neutron Scattering at SINQ, PSI

Motivation: Probe Atomic Scale Structures & Interactions

- We employ a range **neutron and X-ray scattering** techniques to determine the magnetic correlations and underlying interactions behind the quantum phenomena.
- The instrument suite at SINQ enables us to perform both powder and single crystal diffraction and spectroscopy.

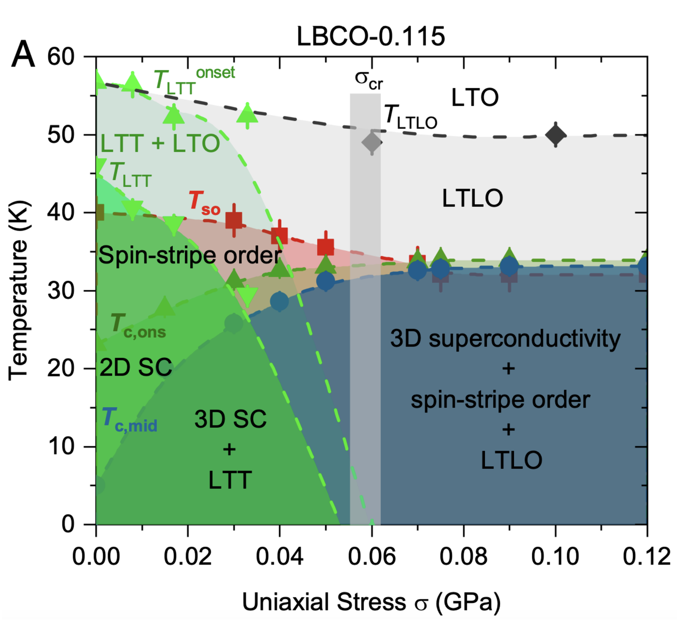


(top) Instrument suite of SINQ (bottom) Swiss Spallation Neutron Source SINQ

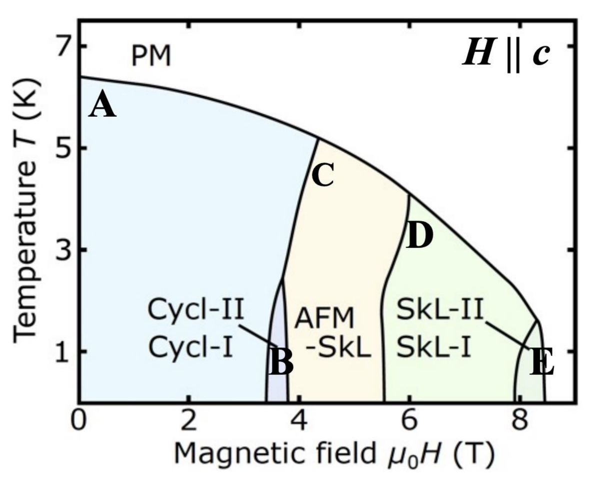
Emergent Quantum Behaviour

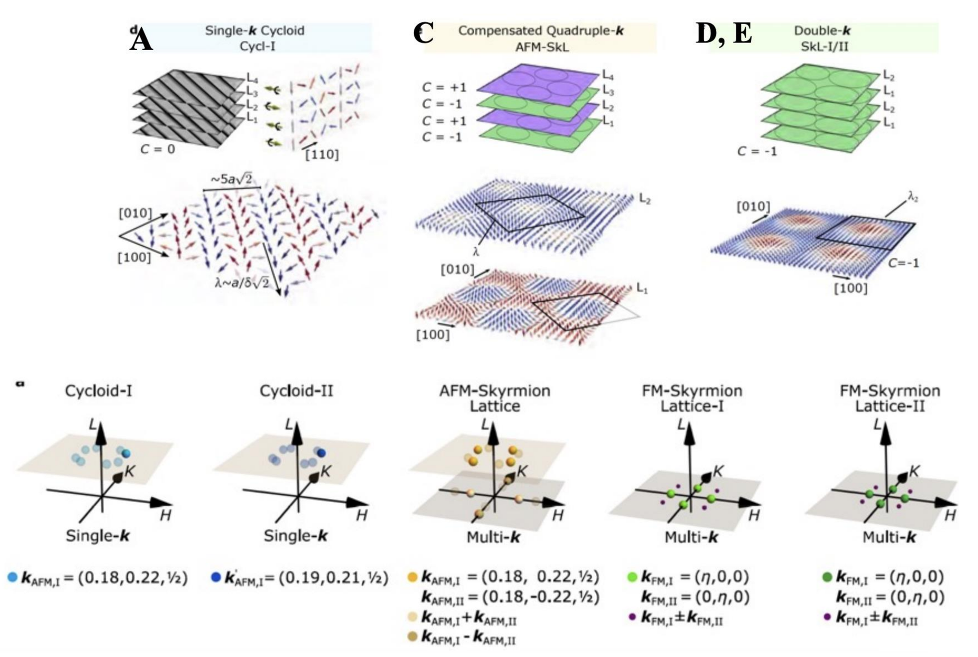
Motivation: Understand and tune the underlying interactions

- By measuring and thus understanding the **interplay between the underlying interactions**, we can determine the cause of these quantum phenomena.
- Using **external parameters**, we can establish the boundaries of these **exotic states** and build phase diagrams.
- These properties can then be manipulated and tuned and even exploited for future application.

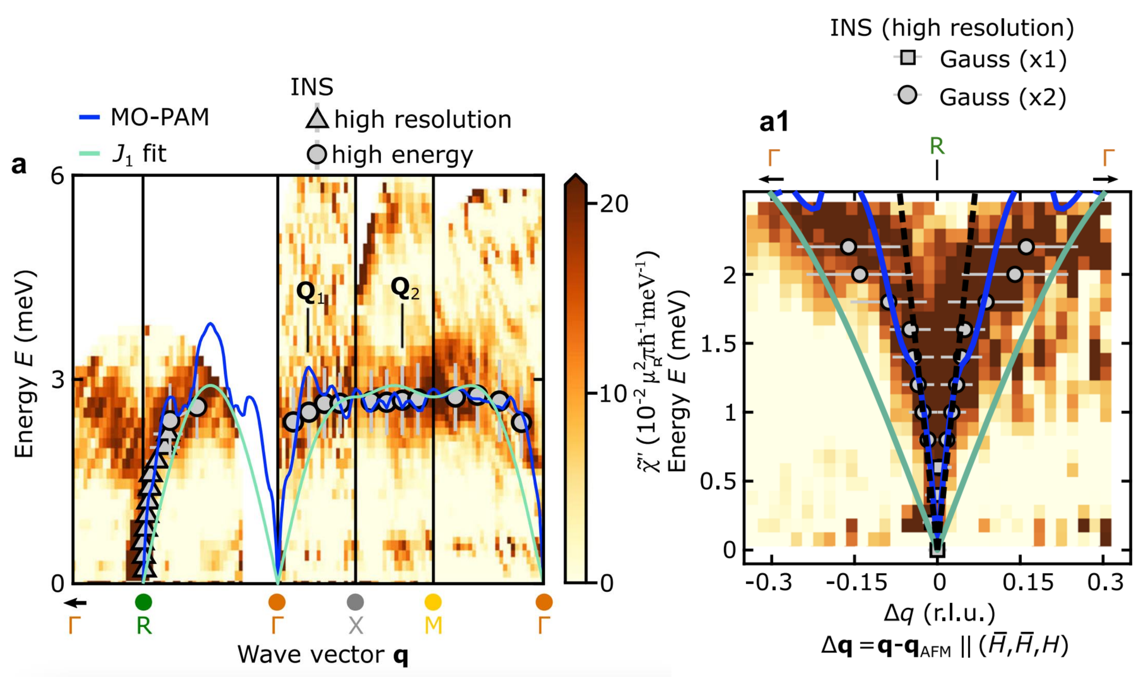


Phase diagram of the stripe-ordered cuprate $La_{2-x}Ba_xCuO_4$ under uniaxial stress, Z. Guguchia *et al.* PNAS. 121 1 (2024)





Magnetic phase diagram and corresponding magnetic textures of $CeAgBi_2$, W. Simeth *et al.* In Review (2024)



A microscopic Kondo lattice model for the heavy fermion antiferromagnet $CeIn_3$, W. Simeth *et al.* Nature Comm. 14:8239 (2023)