Max Planck Research Group

Physics of Unconventional Metals and Superconductors

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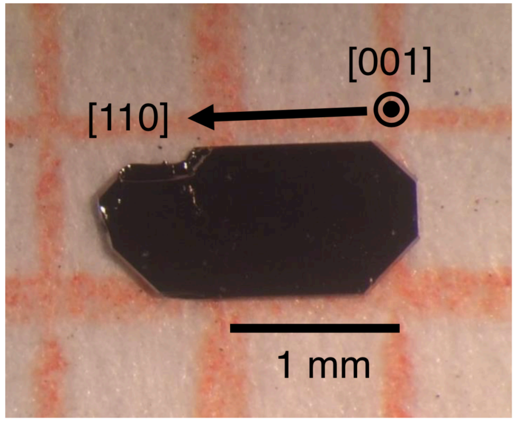
Group leader at MPI Chemical Physics of Solids (since 2014)
Assistant Professor at Technical University Munich (since 2016)

Nov. 2021

MAX-PLANCK-GESELLSCHAFT

Quantum states of matter: example $CeRh_2As_2$

Seunghyun Khim
Group leader PQM
material synthesis



Strong correlations – effective masses of 100 - 1000 m_e

Quantum many-body ground states occur

10^{23} interacting electrons

Theory is currently not able to predict those states

Quantum states of matter: example $CeRh_2As_2$

What are the low-temperature properties?

Which ordered phases occur?

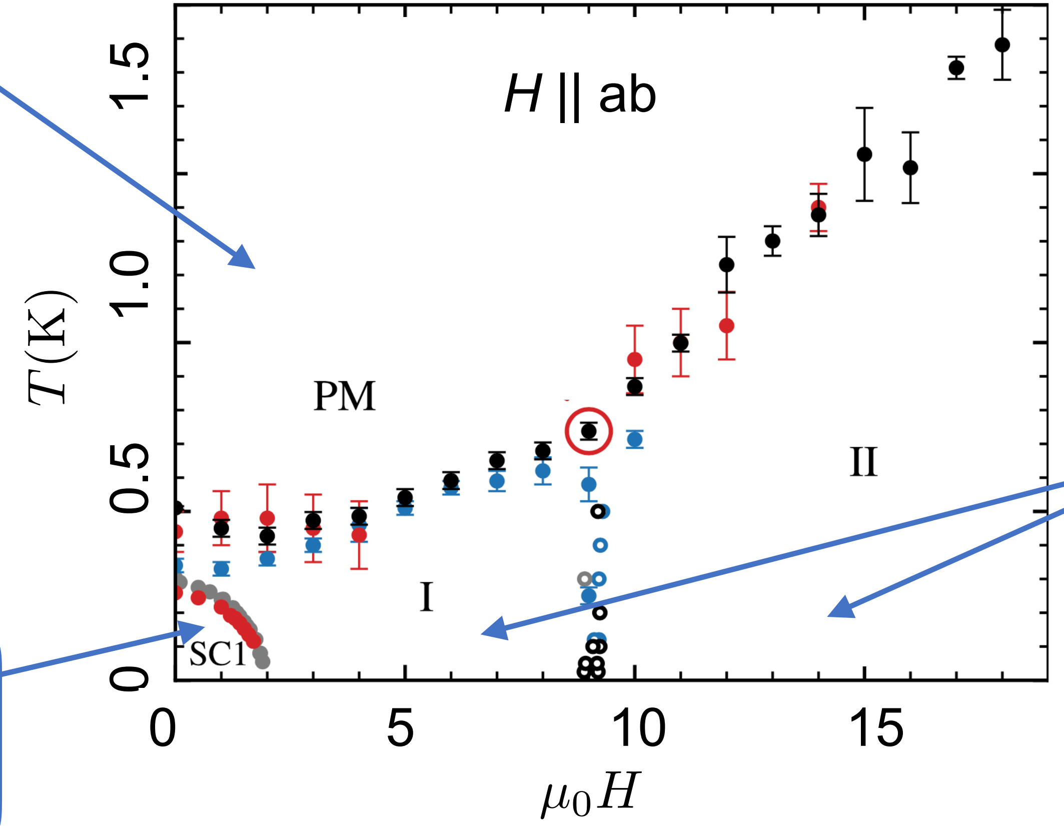
Will the system be an unconventional superconductor?

Experimental information needed!

Quantum states of matter: example $CeRh_2As_2$

Non-Fermi liquid behaviour
Quantum criticality?

Unconventional Superconductivity
Pairing interaction?



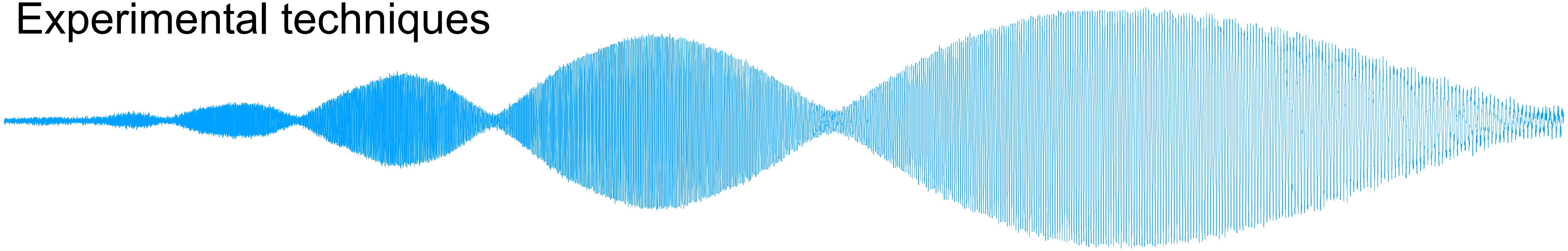
Groundstates with Unconventional order
Quadrupole density wave?

Hafner, …EH… *et al.* arXiv:2108.06267

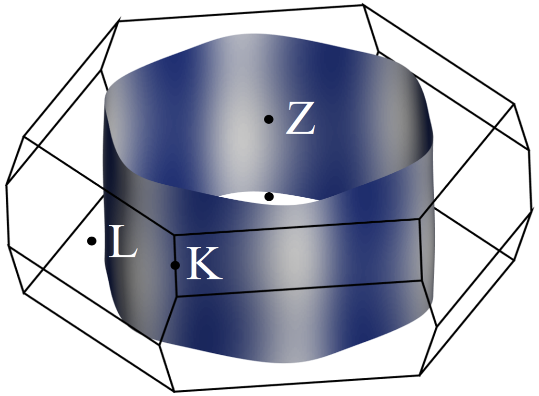
Poster PQM_05

Outline

1. Experimental techniques

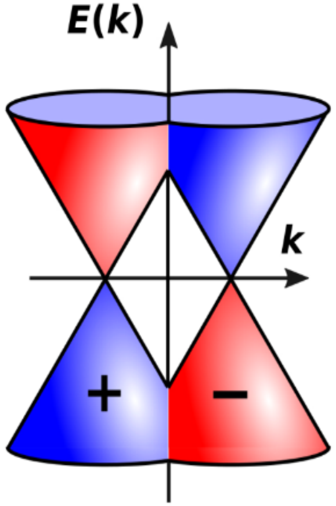


2. Unconventional metals



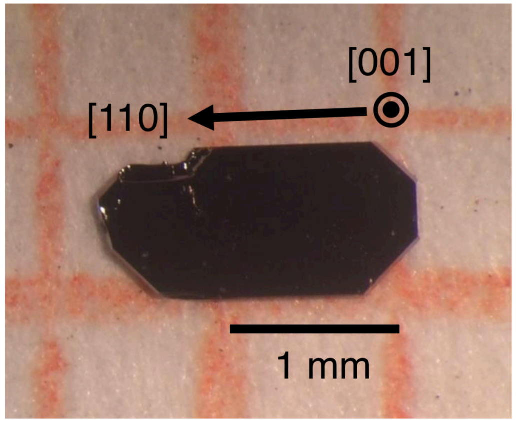
2D Fermi surface in Delafossites

3. Topological phases



Chiral anomaly in Weyl semimetals?

4. Unconventional superconductors



Multiphase superconductivity in $CeRh_2As_2$

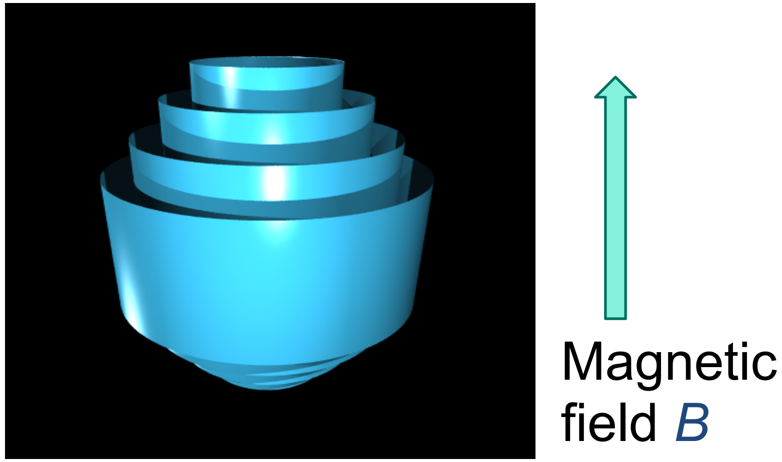
Quantum oscillations, a quasiparticle spectroscopy

Electron-wave function is quantised in a plane perpendicular to magnetic field (Landau 1930)

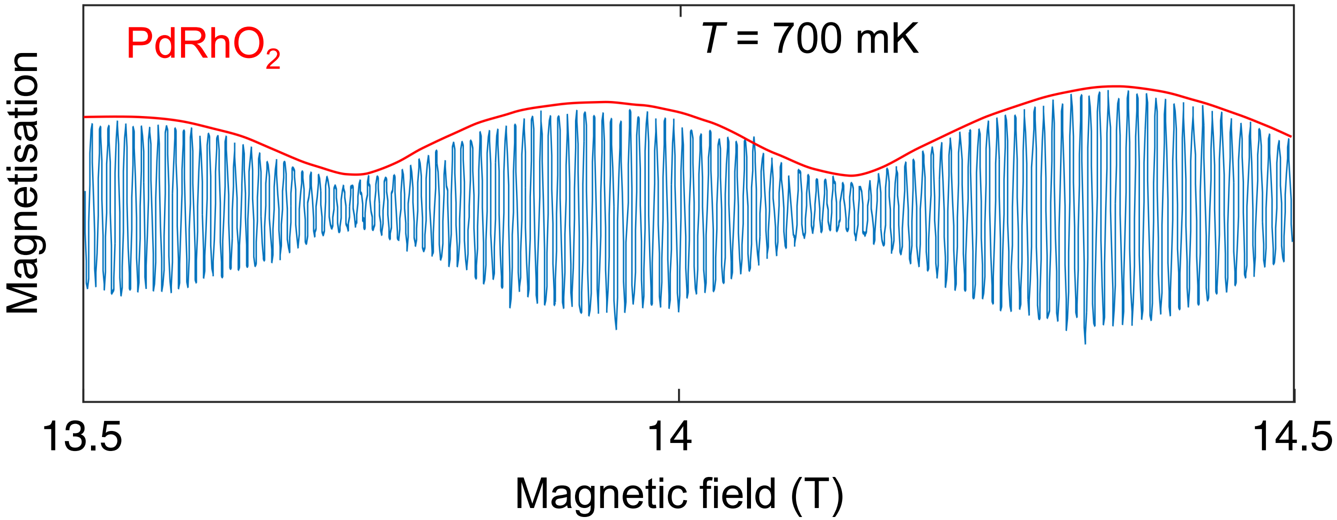
With increasing field, Landau levels move through Fermi energy

=> Oscillations in the density of states

=> Oscillations in magnetisation or resistivity



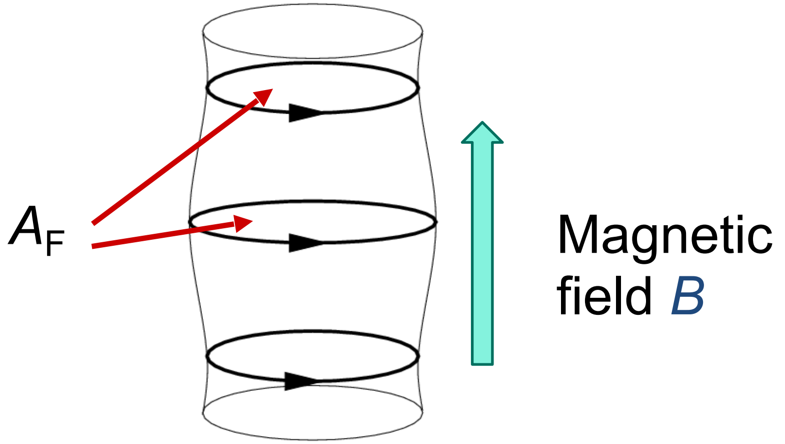
Landau tubes
In reciprocal space



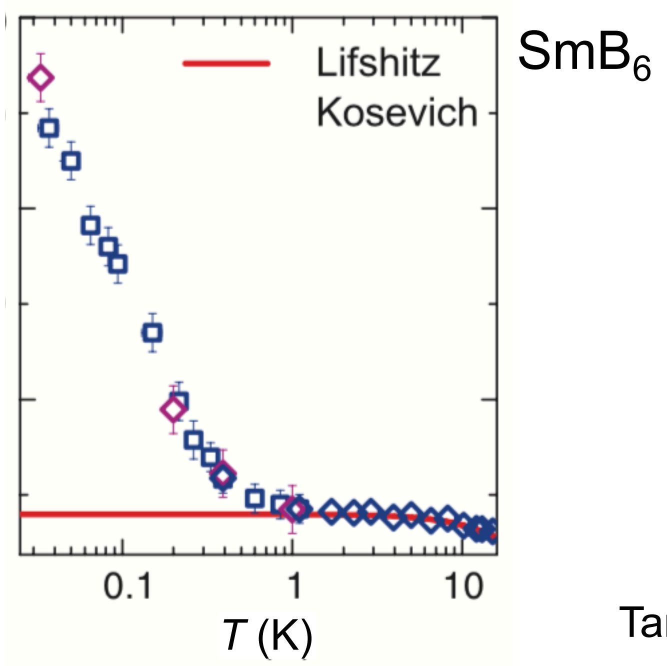
Information from quantum oscillations

- Shape of Fermi surface

$$A_{\mathrm{F}} = \frac{2\pi e F}{\hbar}$$



- Band structure can be compared with theory
- Fermi liquid properties
- Anisotropy
- Interactions
- Scattering processes



Tan *et al.* Science 2015

Technical developments

Very low temperature

$T = 20\,\mathrm{mK}$

Very high magnetic field

$B = 15\,\mathrm{T}$

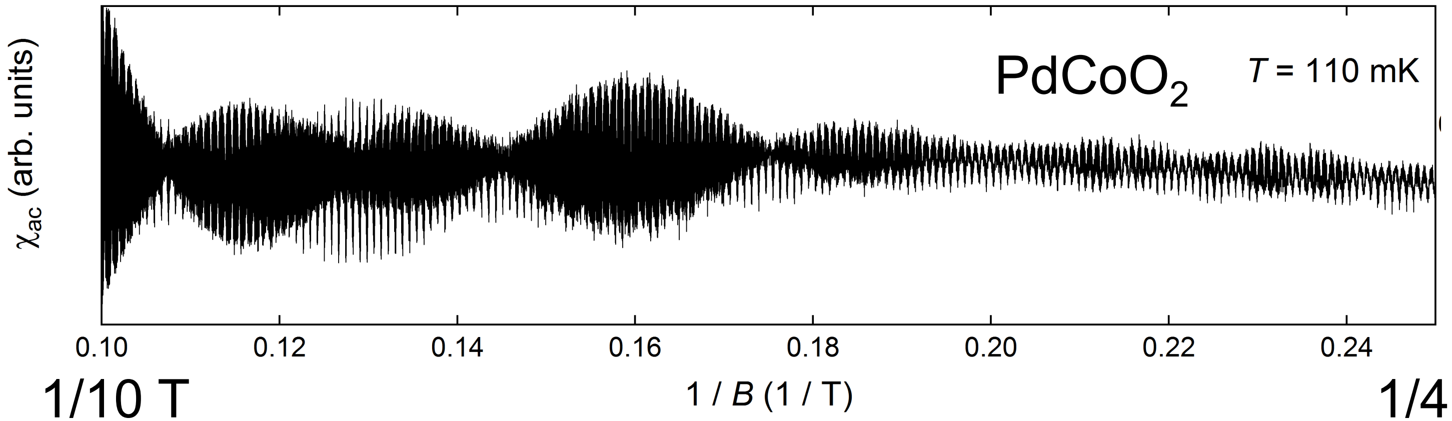
Extremely pure crystals

mean free path $l = 1000\,\text{Å}$

High sensitivity detection techniques

$< V > \approx \mathrm{pV}/\sqrt{\mathrm{Hz}}$

1. Piezoresistive cantilever technique
2. Modulation field technique



1/10 T

1/4 T

Based on ac-susceptibility

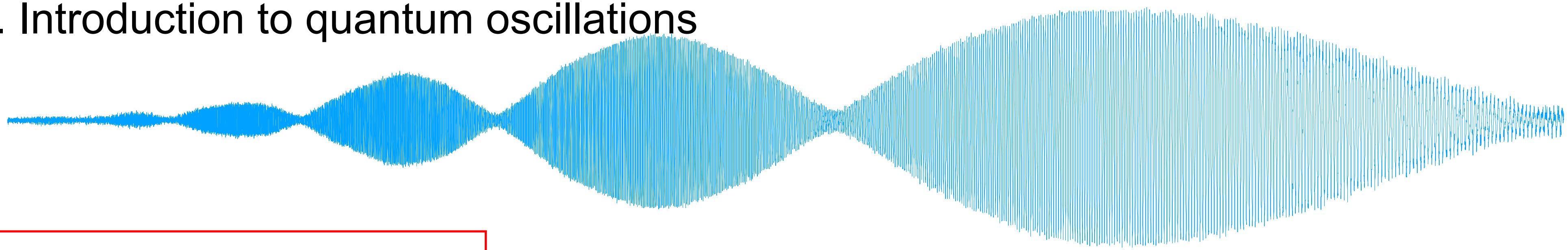
Lower temperature

Can be used in hydrostatic and uniaxial pressure

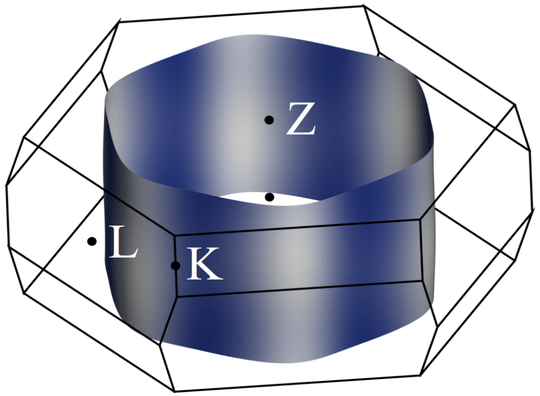
Javier Landaeta

Outline

1. Introduction to quantum oscillations

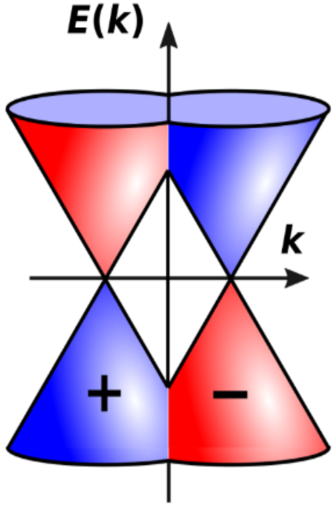


2. Unconventional metals



Fermi surface in delafossites

3. Topological phases



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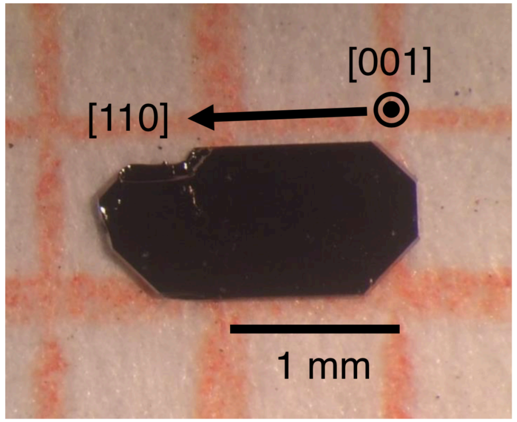
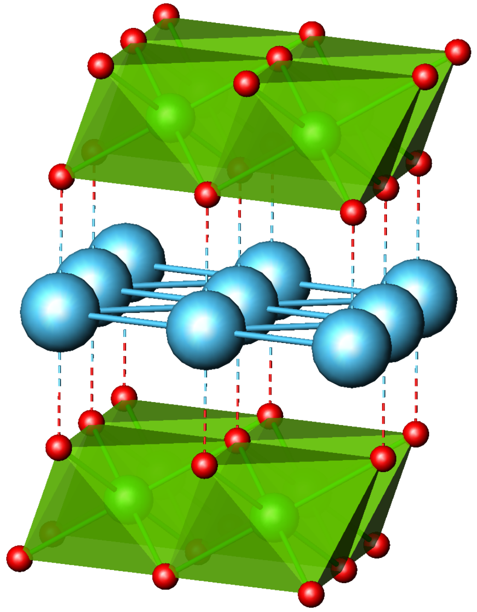


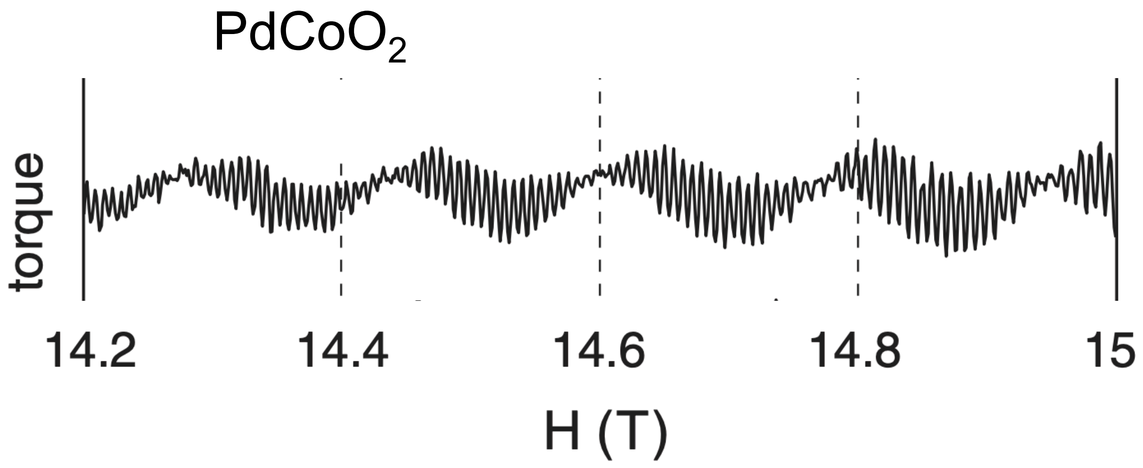
Multiphase superconductivity in $CeRh_2As_2$

Quantum oscillations in delafossites



Delafossites
ABO_2
A = (Pd,Pt)
B = (Co,Cr,Rh)

Highly conductive layers



How two-dimensional is the electronic system?

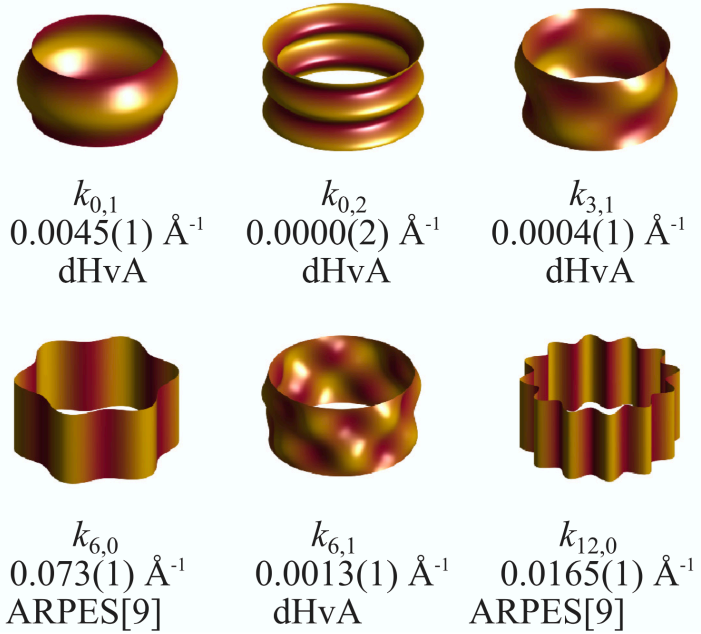
Origin of slow oscillations?

A.P. Mackenzie, Rep. Prog. Phys. 2017

Hicks *et al.* Phys. Rev. Lett. 2012

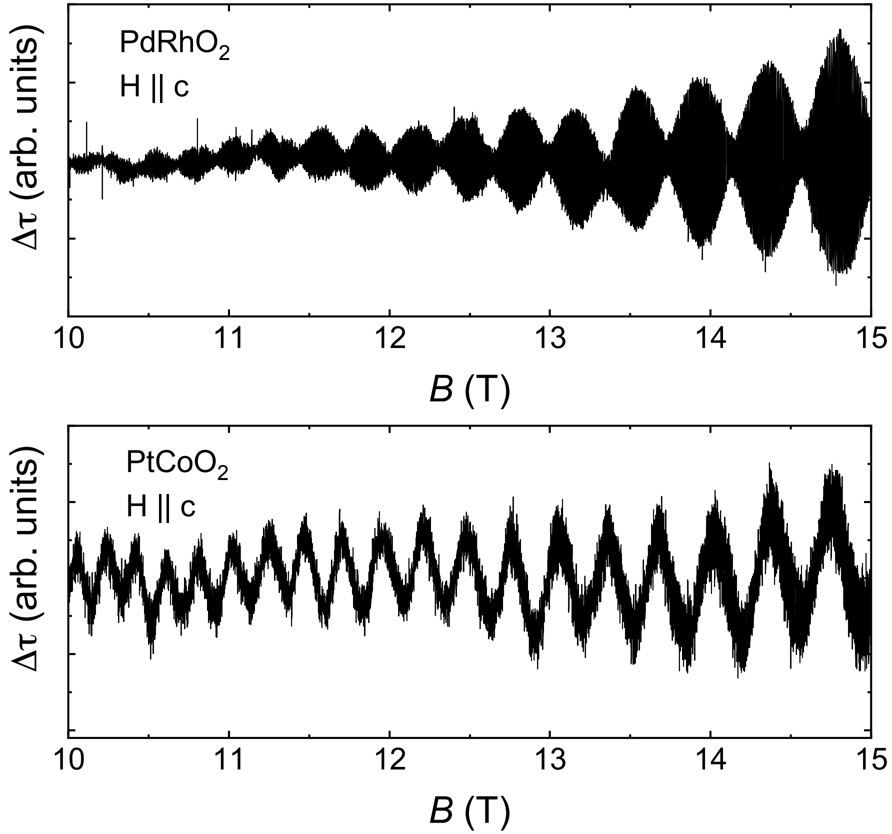
Fermi surface of $PtCoO_2$

Full characterisation



Extremely 2D materials
correlations play important role

Kushwaha, … EH,… King, Sci. Adv. 2015
Arnold, … and EH, PRB 2017
Arnold … and EH, Rev. Sci. Instr. 2018
Arnold, … and EH, PRB 2020*



Frank Arnold

Future: Origin of slow oscillation?
Interactions?

Allocca and Cooper, Phys. Rev. R. 2021

Better sensitivity with modulation technique

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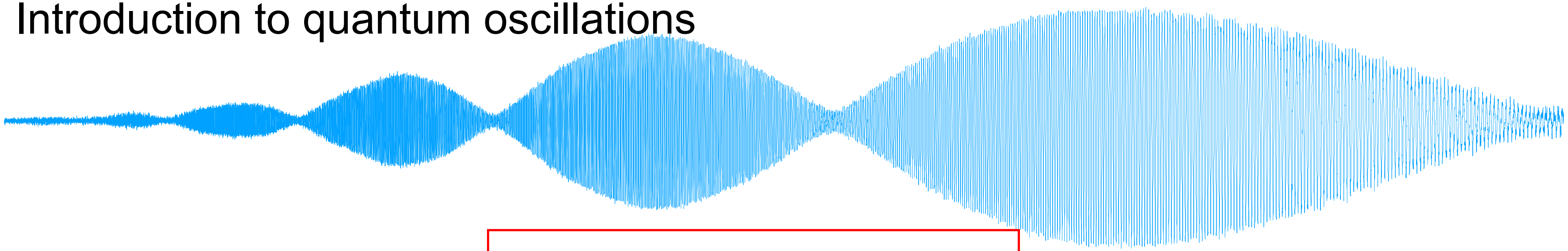

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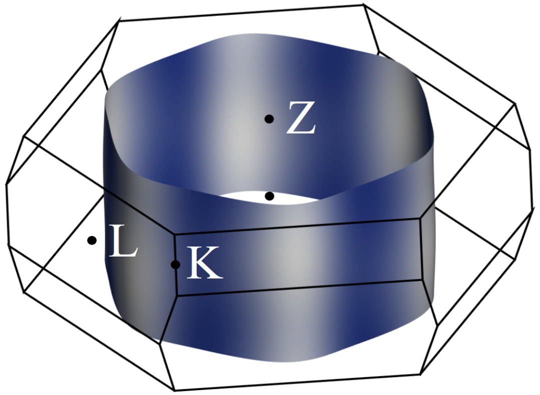

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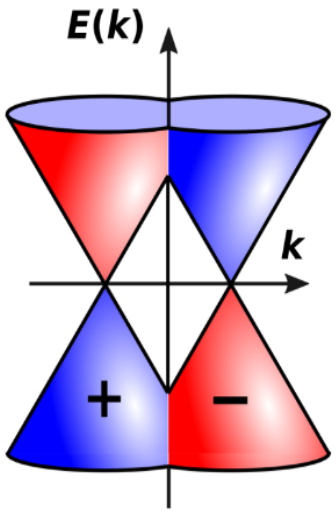

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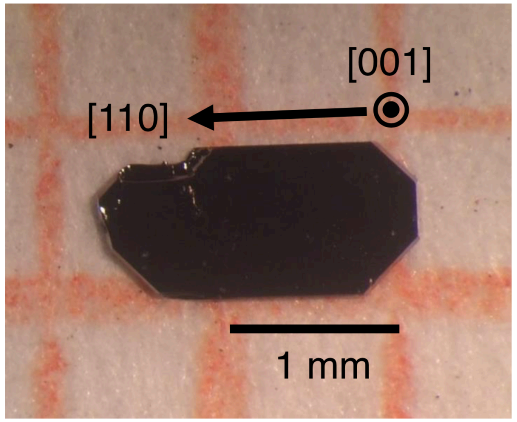
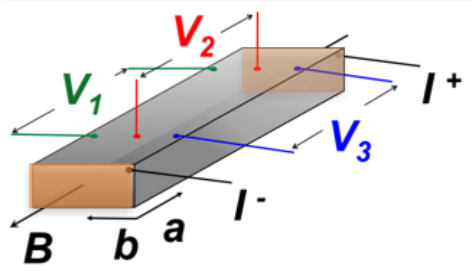


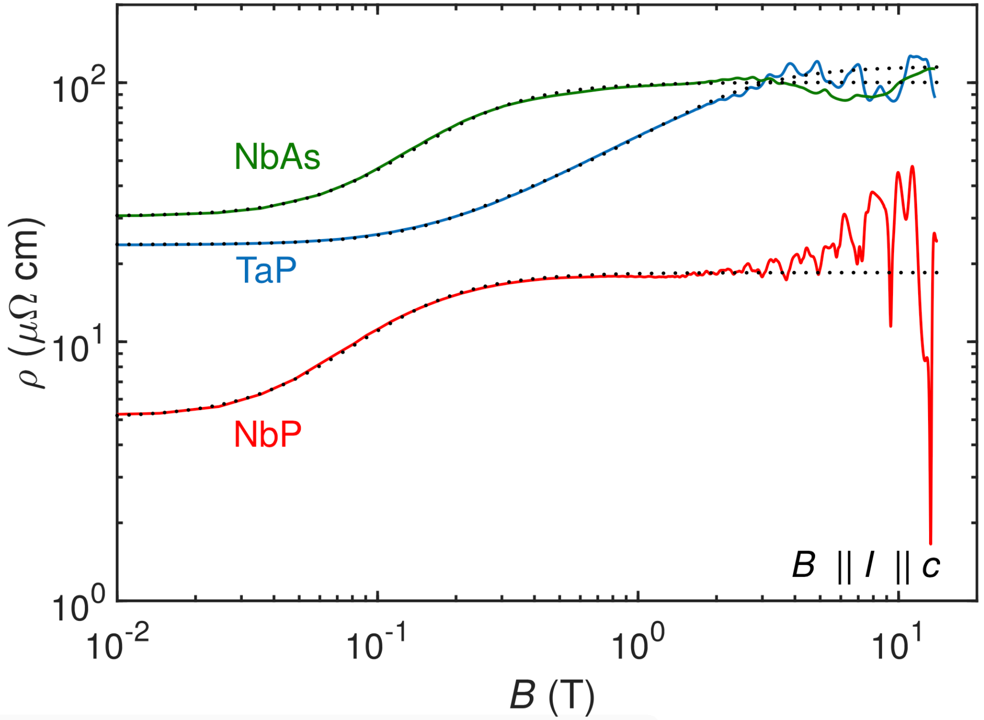
Multiphase superconductivity in $CeRh_2As_2$

Chiral anomaly in longitudinal magnetoresistance?

Aim: Search for chiral anomaly in TaAs family

Homogeneous currents





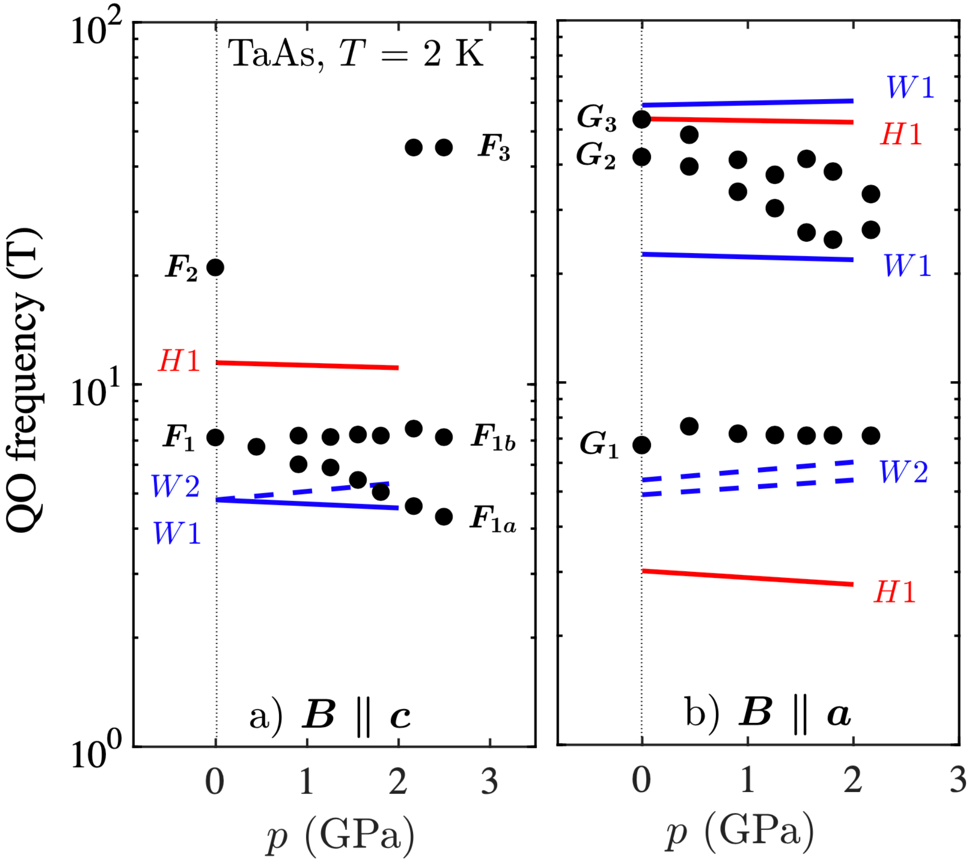
Marcel Naumann

Naumann, …and EH, PRM 2020*
Naumann, … and EH, PRB 2021*
Naumann,… and EH, PSSb 2021*

=> No sign of chiral anomaly!

Weyl node tuning

Distance of the Weyl nodes to the Fermi energy? Johannson *et al.* PRB 2019



Pressure tuning of Weyl nodes through E_F

Possibility to see chiral anomaly under pressure

Zuzana Medvecka

Arnold,… and EH, PRL 2016
Naumann,… and EH, PSSb 2021*
Medvecka, … and EH, in preparation

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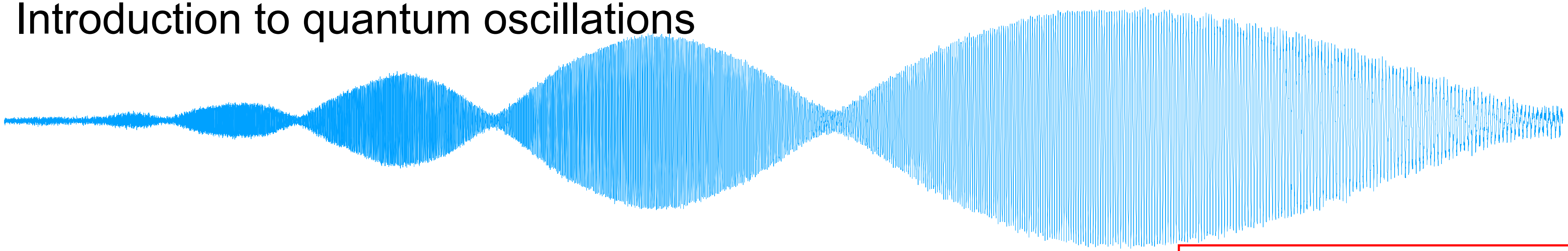

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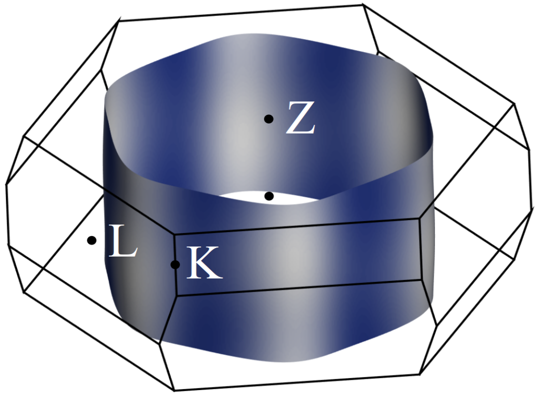

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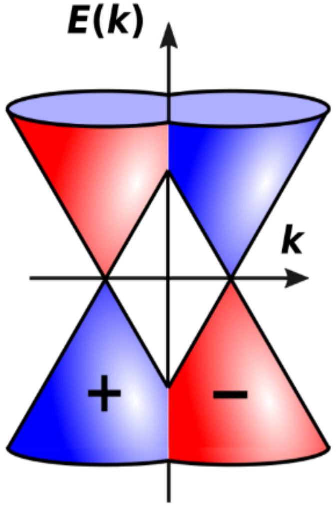

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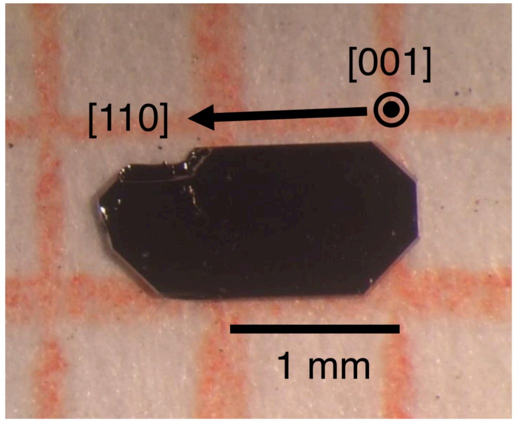
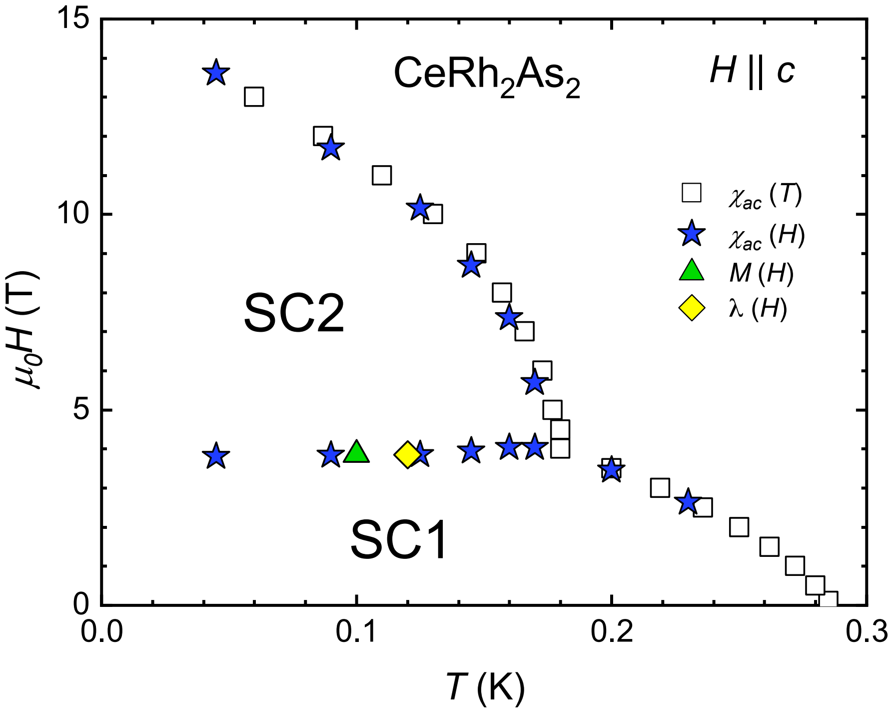


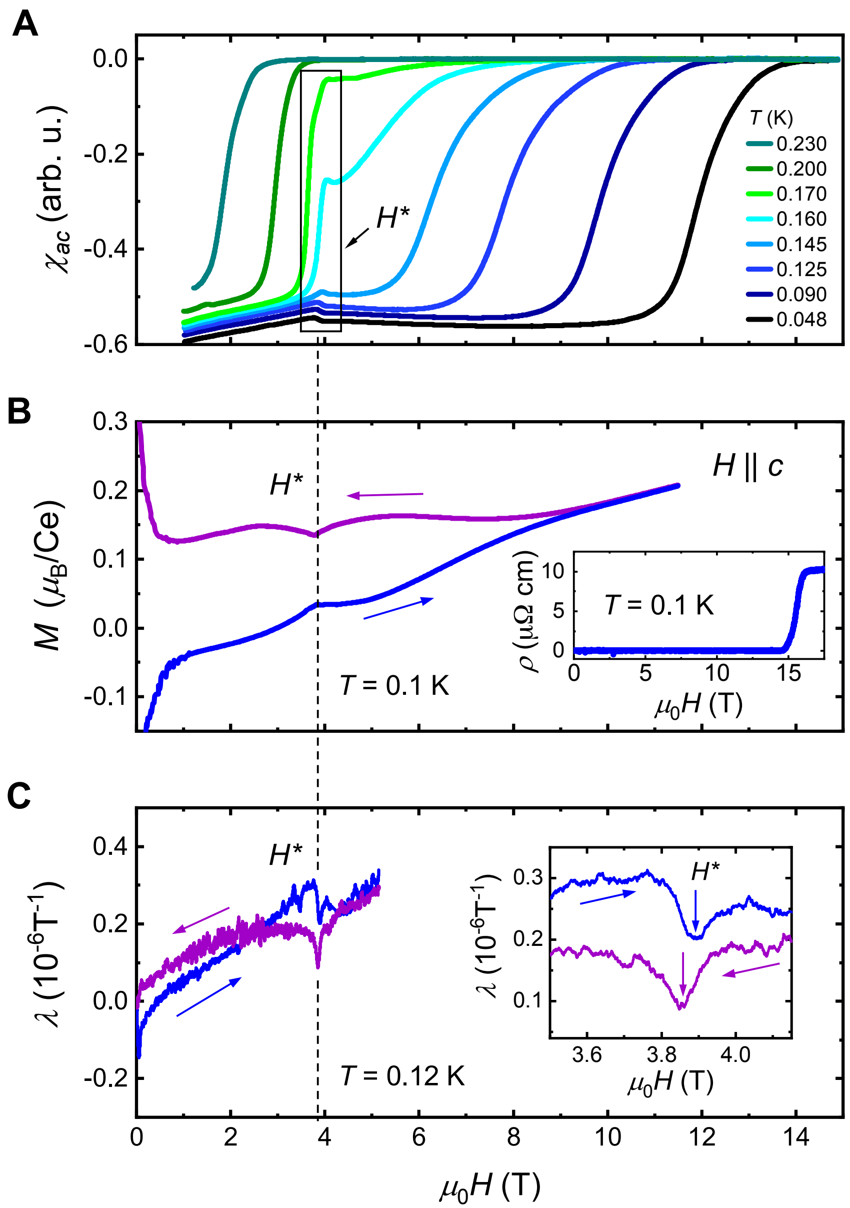
Multiphase superconductivity in $CeRh_2As_2$

Two-phase superconductivity in $CeRh_2As_2$



Thermodynamic phase transition

Posters PQM_05, PUMAS_01

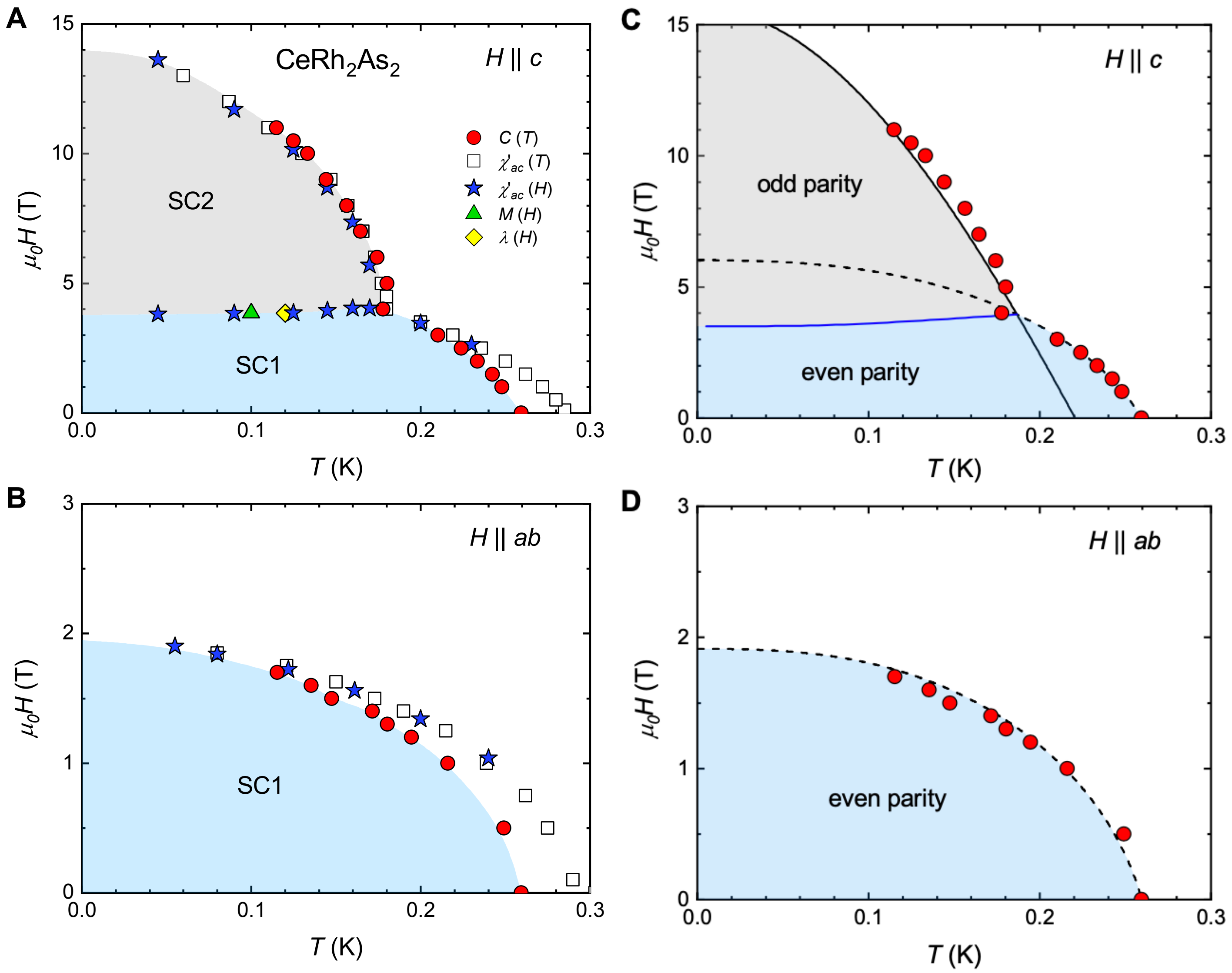


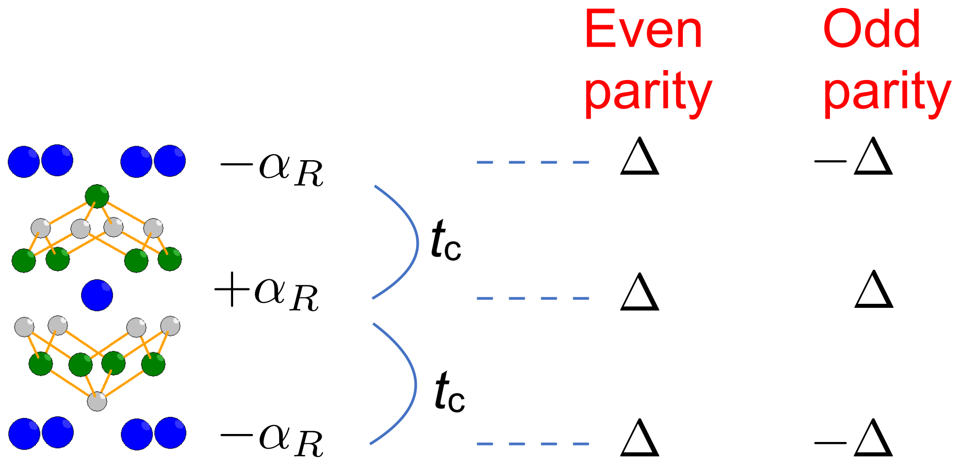
Seunghyun Khim
Group leader PQM
material synthesis

Javier Landaeta

Manuel Brando
Group leader PQM
low temperatures

Phase diagram caused by symmetry





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An unusual material hosts both even and odd superconducting phases

The heavy-fermion crystal combines properties of systems that have inversion symmetry and of those that break it.

Khim, Landaeta … EH, Science 2021
Perspective: Pourret and Knebel, Science 2021
Yoshida, Sigrist, Yanase, PRB 2012

Future / ongoing research

Ongoing work on superconductivity in Sr_2RuO_4 and $CeRh_2As_2$

Poster PUMAS_01

Pressure and strain!

Javier Landaeta

Konstantin Semeniuk

Meike Pfeiffer

Thermal transport down to 40 mK

$YbAlO_3$ - Tomonaga Luttinger liquid candidate

Poster PQM_04

Ulrike Stockert

Parisa Mokhtari

Seita Onishi

Stockert *et al.* PRB 2020

Thanks to my group and collaborators!

Meike Pfeiffer EH Parisa Mokhtari Javier Landaeta Seita Onishi Konstantin Semeniuk Ulrike Stockert

Alumni

Zuzana Medvecka

Frank Arnold

Marcel Naumann

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Fermi-NEst
DFG-ANR

Thank you for your attention!