TECHNISCHE UNIVERSITÄT DRESDEN

ct.qmat Complexity and Topology in Quantum Matter

Fakultät Physik

Workshop
“Tieftemperaturphysik komplexer Elektronensysteme“

When: **13.07.2021, 09:15 – 11:40 Uhr**
Where: **Zoom Meeting**

https://tu-dresden.zoom.us/j/85193786651?pwd=Q0V0KzR2emsyRnhvdzdLRDdTSnBaZz09
Meeting ID: 851 9378 6651
Passcode: reG3NboG#N

13.07.2021

09:15 - 10:00 **Prof. Dr. Silvia Haindl**
Tokyo Institute of Technnology
Title: **From Fe-based Superconductors to Topological Materials**

10:05 - 10:50 **Dr. Mahmoud Abdel-Hafiez**
Uppsala University, Sweden
Title: **Controlling Quantum Materials with Extreme Conditions**

10:55 – 11:40 **Prof. Dr. Elena Hassinger**
MPI CPfS Dresden
Title: **Unconventional states in quantum materials**

Prof. Dr. Silvia Haindl
Tokyo Institute of Technology, Japan

Title:
From Fe-based superconductors to topological materials

Abstract:

More than one decade the material class of Fe-based superconductors has provided a fruitful platform for the investigation of the interplay between charge, spin and orbital degrees of freedom. Electronic properties governed by the Fe 3d states manifest themselves in a rich electronic phase diagram and electronic correlations, which are tunable across the different Fe-pnictide and Fe-chalcogenide compounds. Latter have attracted wide attention with high-temperature superconductivity in 1 uc FeSe/$SrTiO_3$ platforms as well as with predictions of topological phases (band inversions) in FeSe and $FeSe_{1-x}Te_x$.

Topological materials can be classified by symmetries, and due to an intensified research, many different compounds (semiconductors, complex oxides, iridates, 2D layered structures, etc.) and hybrid structures with large spin-orbit coupling were identified for showing topologically protected surface (edge) states and realizing Dirac (Weyl)-like dispersions as well as Berry phase physics in condensed matter. Displayed anomalous electrical transport and magnetic properties include an anomalous metal behavior in superconductor-to-insulator transitions due to potential bosonic topological insulators in 2D electronic systems, unconventional and topological superconductivity, localization effects, quantum anomalous Hall effect or Nernst effect, etc. Interesting questions address the role of disorder, transitions between different (topological) phases and the electrical response upon the irradiation with light.

In my talk I will cover selected previous work on Fe-based superconductors and point out possible future topics on topological and complex materials that contribute to *ct.qmat* center activities.

Dr. Mahmoud Abdel-Hafiez
Uppsala University, Sweden

Title:
Controlling Quantum Materials with Extreme Conditions

Abstract:
Understanding the fundamental properties in novel quantum materials and the development of methods to characterize and control their collective behavior is a topical area that attracts enormous interest. Quantum materials couples the complex electronic, structural, and magnetic components that are often collective and emergent, making them very suitable to manipulate their properties for a range of new electronics. Extreme conditions, particularly very low temperatures associated with large applied pressure and high magnetic fields, have emerged as powerful tools to induce new functionalities in quantum materials and show ways to control their properties.

In this talk, I will describe recent experiments performed in our low temperature laboratory that address how extreme conditions can provide new insights into various fundamental problems respond to new exotic states driven by extreme conditions. First, I will discuss the relation between charge density waves and superconductivity in transition-metal dichalcogenides through high pressure [1] and low temperature experiments down to 60 mK [2-4]. Second, I will present our experiments on the transport and magnetic properties in oxypnictides [5] and Fe-based materials [6] that led to outstanding results on pressure induced suppression of superconductivity on the verge of magnetic ordering [7].

At the end, I will show how my future planned research fits *exactly* with the research directions of the *ct.qmat* excellence cluster "Complexity and Topology in Quantum Matter" at TU Dresden. Importantly, my research goals will undeniably promote and sustain a much-needed synergy between various theoretical and experimental research directions that involve scientists at the *ct.qmat*, as well as with national and international collaborators at TU Dresden.

[1] M. Abdel-Hafiez *et al*., *Sci. Rep.* **6,** 31824 (2016)
[2] Y. Kvashnin *et al*., *Phys. Rev. Lett.* **125**, 186401 (2020)
[3] A. Majumdar *et al*., *Phys. Rev. Materials* **4**, 084005 (2020)
[4] C. Cho et al., *Nat. Commun.* **12,** 3676 (2021)
[5] A. Adamski, C. Krellner, and M. Abdel-Hafiez, *Phys. Rev.* B **96**, 100503(R) (2017)
[6] Derrick Van Gennep *et al*., *Phys. Rev. B* **101**, 235163 (2020)
[7] M. Abdel-Hafiez *et al*., Phys. Rev. B **98**, 094504 (2018)

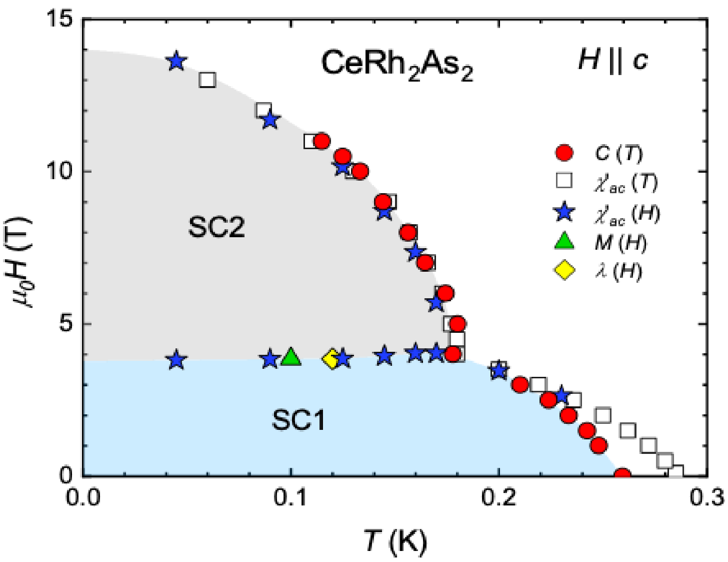
Prof. Dr. Elena Hassinger
MPI CPfS Dresden

Title:
Unconventional states in quantum materials

Abstract:
The discoveries of new materials with unexpected properties have always driven the advancement of technology. To give an example, liquid crystals were found in 1888, have been investigated since then and are now used in all LCD displays. Today, one group of materials where new phases occur are so-called quantum materials. In these, the appearance of unconventional states of matter is related with the fact that electrons interact strongly with each other. My group's motivation for research is to understand this intriguing relation. In particular, we are interested in unconventional superconductivity and unconventional metallic states such as topological systems, heavy-Fermi and non-Fermi liquids. In my talk I will mainly focus on two groups of materials, namely topological semimetals and heavy fermion systems. In topological systems, the low energy excitations behave like relativistic particles and hence allow to investigate predictions from high energy physics. Our aim here is to find evidence for Weyl fermionic behavior in bulk experimental probes like low-temperature resistivity. In heavy fermion systems, superconductivity evolves out of unconventional ground states. In these materials we are interested in non-Fermi liquid behavior near quantum critical points and unconventional superconducting states.
My group's expertise lies in high sensitivity - low temperature measurements and especially in the detection of quantum oscillations in metals. These oscillations are a direct consequence of the quantization of the electron orbits in a magnetic field. We measure thermodynamic and transport probes such as magnetic susceptibility, torque or resistivity. These techniques yield macroscopic information on the appearing phases. Additionally, quantum oscillations can be detected in those measurements if requirements of extremely pure materials, low temperatures, high magnetic fields and low noise levels are fulfilled. My group is one of the few in the world specialized in this quasiparticle spectroscopy that gives microscopic information on the energy eigenstates, scattering processes and the interactions between charge carriers in the metal.
In this talk I will present how we have been using these experimental techniques to answer the scientific questions mentioned above. Investigations of the topological **Weyl semimetals** TaAs, TaP, NbAs and NbP, have allowed to test if the chiral anomaly, a theoretical prediction from high-energy physics, induces a longitudinal magnetoresistance. This response should depend on the energy eigenstates of the electrons in these materials. Therefore, we have established the latter via quantum oscillations and hence were able to show that in TaAs and

NbAs, electrons behave like Weyl fermions [1,2]. Additionally, our group has found evidence that an apparent negative longitudinal magnetoresistance can easily arise from an inhomogeneous current distribution caused by the extreme field-induced resistivity anisotropy typical for any compensated semimetal [1,3]. We succeeded revealing that when the current is flowing homogeneously, the magnetoresistance does not show clear signs of the chiral anomaly [4].

Unconventional superconductivity (SC) remains one of the most intriguing phenomena in condensed matter physics. We have recently discovered $CeRh_2As_2$, an outstanding unconventional superconductor [5]. This compound, which probably presents quadrupole order at around 0.4 K is locally non-centrosymmetric at the Ce-position while keeping an overall centrosymmetry. The superconducting state evolves below 0.26 K. Most peculiarly, it has two superconducting states as a function of magnetic field B||c and a critical field curve presenting a sharp kink at 4 T and increasing up to 14 T (see the figure). In my talk I will give details about this discovery and how it can be understood when considering that the local symmetry can give rise to spin-orbit interaction.



[1] F. Arnold *et al.*, Nat. Commun. (2016)
[2] F. Arnold *et al.*, Phys. Rev. Lett. (2016)
[3] R. D. dos Reis *et al.*, New J. Phys. (2016)
[4] M. Naumann *et al.*, Phys. Rev. Mat. (2020)
[5] S. Khim *et al.*, submitted (2020)