1st Symposium on Correlated Quantum Materials & Solid State Quantum Systems

February 22-23, 2023

Technische Universität Wien

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Q-M&S

Hopes are high that quantum computers will revolutionize conventional computation and data processing. Although they can already perform certain computations faster than conventional computers, more robust solid state quantum systems are needed to solve the problem of quantum error correction and fully exploit the potential of quantum computing. A currently disjunct field are correlated quantum materials. These are designer materials with properties due to quantum effects of strongly interacting electrons. They represent a highly active but particularly complex area of fundamental solid state physics.

The SFB Correlated Quantum Materials & Solid State Quantum Systems (Q-M&S) aims to connect both are-as. Concepts and methods developed in the context of quantum information and computation will contrib-ute to a better understanding of correlated quantum materials. For example, “entanglement meters” will be de-vised to unravel the mystery of the strange metal state. In turn, research will be conducted into how corre-lated quantum materials can be used for quantum applications. Correlated quantum materials with topologi-cal properties for instance could lead to very robust and well-controllable quantum devices in novel hybrid systems.

The 1st Symposium on Correlated Quantum Materials & Solid State Quantum Systems is the kick-off event of the SFB Q-M&S, which is funded by the Austrian Science Fund (FWF) and the German Research Founda-tion (DFG). It features keynote and invited talks by speakers from both fields, short presentations of the 10 PIs of the SFB, and flash presentations by some of their team members. There will be ample time for dis-cussion, to engage in fruitful dialogue and build bridges between disciplines.

Program

Wednesday, February 22, 2023

https://tuwien.zoom.us/j/91026833063?pwd=Vm1HZTdUNzI3WkxvM2ZITXFLbjUzQT09	
09:00-09:20	Opening
Chair:	Karsten Held
09:20-10:00 (30+10)	Claudia Felser, Max-Planck-Institute for Chemical Physics of Solids *Chirality and topology*
10:00-10:40 (30+10)	Marcus Huber, Technische Universität Wien *Entanglement theory beyond two qubits*
10:40-11:10	Coffee break
Chair:	Kimberly Modic
11:10-11:50 (30+10)	Jedediah H. Pixley, Rutgers University *Entanglement of the Kondo effect: its destruction and implication*
11:50-12:30 (30+10)	Wolfgang Belzig, University of Konstanz *Quantum squeezed magnons and hybridization of singlet-triplet Cooper pairs in low-dimensional materials*
12:30-14:00	Lunch break
Chair:	Zhanybek Alpichshev
14:00-14:40 (30+10)	Alexander Brinkman, University of Twente *Topological quantum information engine – theory and experiment*
14:40-15:00 (15+5)	Elke Scheer, University of Konstanz *Gate control of supercurrents*
15:00-15:20 (15+5)	Georgios Katsaros, Institute of Science and Technology Austria *Understanding the physics of hybrid semiconductor-superconductor devices*
15:20-16:00	Coffee break
Chair:	Neven Barišić
16:00-16:20 (15+5)	Andrew P. Higginbotham, Institute of Science and Technology Austria *Superconductivity from a melted insulator*
16:20-16:40 (15+5)	Maksym Serbyn, Institute of Science and Technology Austria *Multilayer graphenes as a platform for superconductivity*
16:40-17:00 (15+5)	Kimberly Modic, Institute of Science and Technology Austria *Thermodynamic studies of quantum spin liquids*
17:00-17:20 (15+5)	Fakher F. Assaad, Julius-Maximilians-Universität Würzburg *Dimensional mismatch Kondo systems*
17:20-18:00	Informal discussions
19:00-22:00	Symposium dinner

Thursday, February 23, 2023

https://tuwien.zoom.us/j/91026833063?pwd=Vm1HZTdUNzI3WkxvM2ZITXFLbjUzQT09	
Chair:	Elke Scheer
09:00-09:20 (15+5)	Karsten Held, Technische Universität Wien *Dynamical vertex approximation for quantum criticality*
09:20-09:40 (15+5)	Neven Barišić, Technische Universität Wien, University of Zagreb *Dual nature of charges in high-T_c cuprates*
09:40-10:00 (15+5)	Zhanybek Alpichshev, Institute of Science and Technology Austria *Nonlinear spectroscopy of strongly correlated systems*
10:00-10:20 (15+5)	Silke Paschen, Technische Universität Wien *Strange metal heavy fermion compounds*
10:20-10:50	Coffee break
Chair:	Maksym Serbyn
10:50-11:50	Flash presentations by SFB Juniors - Group Alpichshev (P2): TBA - Group Assaad (P3): Sounak Biswas - Group Barišić (P4): Luka Akšamović - Group Held (P5): Martin Brass - Group Higginbotham (P6): Sue Shi - Group Katsaros (P7): Marco Valentini - Group Modic (P8): Shiva Safari - Group Paschen (P9): Lukas Fischer - Group Scheer (P10): Ronja Fischer-Süßlin / Roman Hartmann - Group Serbyn (P11): Serafim Babkin
11:50-12:20 (25+5)	Norbert Schuch, University of Vienna *Entanglement and topological order in many-body systems*
12:20-13:50	Lunch break
Chair:	Fakher F. Assaad
13:50-14:20 (25+5)	Marta Gibert, Technische Universität Wien *Critical length scales at metal-insulator and magnetic oxide interfaces*
14:20-15:00 (30+10)	Philip Walther, University of Vienna *Photonic quantum computing – a bright future for many applications*
15:00-15:30	Coffee break and farewell for all but SFB-PIs
15:30-16:30	SFB Executive Board Meeting
16:30-18:30	Laboratory tours/informal discussions, etc.
19:00-22:00	Symposium dinner for SFB PIs

Abstracts

Alpichshev, Zhanybek

Nonlinear spectroscopy of strongly correlated systems

I this talk I will discuss how nonlinear optical methods can provide novel information about the microscopic details of strongly correlated systems on the example of candidate-Kitaev-spin-liquid compounds. In conclusion I will discuss the motivation for extending the experiments to the far-infrared (THz) frequency range essential for the current SFB project.

Assaad, Fakher F.

Dimensional mismatch Kondo systems

Consider d-dimensional Heisenberg model, with exchange interaction J_h, embedded in a d+1 dimensional Fermi liquid and Kondo coupling J_k. For d=1 this corresponds to chains of magnetic adatoms on metallic surfaces, and for d=2 to Kondo heterostructures. We will argue that these systems host a rich set of quantum phase transitions including Kondo destruction transitions as well as Hertz-Millis type transitions.

Barišić, Neven

Dual nature of charges in high-T_c cuprates

The experimentally established universalities in high-T_c cuprates will be presented. Based on them we show that the phenomenology of cuprates across the phase diagram is fully captured by the charge conservation relation:

$$1 + p = n_{loc} + n_{eff}$$

with the superfluid density that simply corresponds to:

$$\rho_S = n_{eff} \cdot (O_S\, n_{loc})$$

where p is doping, n_{eff} is the carrier density, which can be directly determined experimentally, while O_S is a compound-dependent constant. n_{loc} is density of localized charge within a CuO_2 plaquette, and is responsible for all the strangeness of these compounds, which includes the pseudogap phenomenon and the superconducting glue.

Belzig, Wolfgang

Quantum squeezed magnons and hybridization of singlet-triplet Cooper pairs in low-dimensional materials

Tailoring magnetic and superconducting excitations by geometric confinement in combination with external fields is a key to create novel functionalities and unusual quantum states. First, we will show that magnons can form squeezed quantum states due to simple geometric confinement or antiferromagnetic couplings. Long-range magnetic interactions can lead to a contactless coupling that might be useful for quantum information transfer. Second, we discuss superconductors in two dimensions with strong spin-orbit interactions that are in a mixed singlet-triplet pair states of the Ising type. Magnetic fields and other pairing channels lead to the formation of novel finite-energy pairing states. These states can be probed experimentally through a high-energy ‚mirage'-gap.

Brinkman, Alexander

Topological quantum information engine – theory and experiment

Because of spin-momentum locking at topological edges or surfaces, an electronic current can polarize nuclear spins upon scattering. Vice versa, an initially polarized nuclear spin registry, upon relaxation, can drive an electrical current. We theoretically propose a system that can ideally operate at the Landauer limit; the heat dissipation required to erase one bit of information stored in the nuclear spin memory approaches $k_BT \ln 2$. Furthermore, we model that all energy stored in the memory, $k_BT \ln 2$ per one bit of information, can be extracted in the form of electrical work.

Experimentally, we pursue the topological quantum information engine by employing the topological insulator $Bi_{1-x}Sb_xTe_3$. Ultrasmooth films are grown by molecular beam epitaxy. The Fermi energy can be gate-tuned throughout the Dirac cone. We will discuss experimental indications for nuclear spin polarization at the topological surfaces. In the regime of ultrathin $Bi_{1-x}Sb_xTe_3$ a hybridization gap is formed at the topological surfaces. We aim to tune the hybridization such that topological edge states appear.

Felser, Claudia

Chirality and topology

Chirality is a very active field of research in organic chemistry, closely linked to the concept of symmetry. Topology, a well-established concept in mathematics, has nowadays become essential to describe condensed matter [1,2]. At its core are chiral electron states on the bulk, surfaces and edges of the condensed matter systems, in which spin and momentum of the electrons are locked parallel or anti-parallel to each other. Magnetic and non-magnetic Weyl semimetals, for example, exhibit chiral bulk states that have enabled the realization of predictions from high energy and astrophysics involving the chiral quantum number, such as the chiral anomaly, the mixed axial-gravitational anomaly and axions [3-5]. Chiral topological crystals exhibit excellent chiral surface states [6,7] and different orbital angular momentum for the enantiomers, which can be advantageous in catalysis. The potential for connecting chirality as a quantum number to other chiral phenomena across different areas of science, including the asymmetry of matter and antimatter and the homochirality of life, brings topological materials to the fore [8].

[1] M. G. Vergniory, B. J. Wieder, L. Elcoro, S. S. P. Parkin, C. Felser, B. A. Bernevig, N. Regnault, Science 2022, 376, 6595.
[2] P. Narang, C. A. C. Gracia and C. Felser, Nat. Mater. 2021, 20, 293.
[3] J. Gooth et al., Nature 2017, 547, 324.
[4] J. Gooth et al., Nature 2019, 575, 315.
[5] D. M. Nenno, et al., Nat Rev Phys 2022, 2, 682.
[6] B. Bradlyn, J. Cano, Z. Wang, M. G. Vergniory, C. Felser, R. J. Cava and B. A. Bernevig, Science 2016, 353, aaf5037.
[7] N. B. M Schröter, et al., Science 2020, 369, 179.
[8] C. Felser, J. Gooth, preprint arXiv:2205.05809.

Gibert, Marta

Critical length scales at metal-insulator and magnetic oxide interfaces

Atomically-engineered heterostructures constitute excellent model systems to investigate fundamental structure-property relations in transition metal oxides and their evolution as the thickness of the constituent layers is reduced to only a few unit cells (u.c.).

To study the characteristic lengths of the two phases involved in metal-insulator transitions (MITs), we grow $NdNiO_3$/$SmNiO_3$ superlattices. These two nickelates undergo MITs at different temperatures in bulk. Transport measurements reveal that a minimum layer thickness of 3 nm is required to observe the two transitions separated in the superlattice; otherwise, only one MIT occurs. This critical length scale is determined by balancing the energy cost of the boundary between a metal and an insulator and the bulk phase energies.[1]

The loss of functionality as thickness is reduced is a long-standing issue most oxides face. We show that films of ferromagnetic insulating La_2NiMnO_6 (LNMO) [3] are still magnetic down to 2 u.c.. However, the magnetic properties of 2-5 u.c. LNMO films are affected beyond dimensionality effects due to an electronic reconstruction at the interfaces. Using a top electron-acceptor layer, the electron excess is redistributed, and the magnetism of the ultrathin LNMO films is restored.[4]

[1] Dominguez et al., Nat. Mater. 19, 1182 (2020).
[2] Mundet et al., Nano Letters 21, 2436 (2021).
[3] De Luca et al., APL Mater. 9, 081111 (2021).
[4] De Luca et al., Adv. Mater. 34, 2203071 (2022).

Held, Karsten

Dynamical vertex approximation for quantum criticality

Strong electronic correlations pose one of the biggest challenges to solid state theory. Recently methods have been developed [1,2] that address this problem by starting with the important local correlations of dynamical mean field theory (DMFT), but further extend it to nonlocal correlations on all length scales. These non-local correlations are generated through Feynman diagrams, with a local two-particle vertex instead of the bare Coulomb interaction as a building block.

Diagrammatic extensions of DMFT have been very successfully used to calculate long-range charge, magnetic, and superconducting fluctuations as well as (quantum) criticality in strongly correlated electron systems.

I will start by giving a brief synopsis of these diagrammatic extensions of DMFT, in particular the first such approach, the dynamical vertex approximation (DΓA). Then I will turn to the calculation of superconductivity, pseudogaps and, in particular, quantum criticality, before providing an outlook on the connected activity in the SFB Q-M&S.

[1] G. Rohringer et al., Rev. Mod. Phys. 90, 025003 (2018).
[2] For a first reading cf. K. Held, arXiv:2208.03174 (Jülich Autumn School 2022).

Higginbotham, Andrew P.

Superconductivity from a melted insulator

I will outline a recent experiment that uses measurement techniques borrowed from superconducting qubits to shed new light on the superconductor-insulator quantum phase transition. In a technologically relevant superconductor-insulator system, we find that superconductivity persists orders of magnitude past the predicted Giamarchi-Schulz transition to an insulator. We quantitatively explain this behavior as arising from the high-temperature limit of a melted insulator.

Huber, Marcus

Entanglement theory beyond two qubits

In this talk, I intend to give an instructive introduction into the field of entanglement theory. Starting from the simplest case, I will generalise to higher-dimensional and multipartite settings, provide operational implications of different notions of entanglement. Finally, I will provide an overview of different methods of entanglement certification, with a focus on many-body systems. The talk will be based upon our recent review of the field (Nature Reviews Physics 1, 72–87 (2019)).

Katsaros, Georgios

Understanding the physics of hybrid semiconductor-superconductor devices

Hybrid semiconductor–superconductor devices hold great promise for realizing Majorana zero modes. However, multiple claims of Majorana detection, based on either tunnelling or Coulomb blockade (CB) spectroscopy, remain disputed. In this talk I will introduce an experimental protocol that allows to perform both types of measurement on the same hybrid island by adjusting its charging energy via tunable junctions to the normal leads. This method reduces ambiguities of Majorana detections by checking the consistency between CB spectroscopy and zero-bias peaks in non-blockaded transport. The results highlight the importance of combined measurements on the same device for the identification of topological Majorana zero modes.

Modic, Kimberly

Thermodynamic studies of quantum spin liquids

I will summarize the current state of Kitaev quantum spin liquids, focusing on experiments performed under in-plane magnetic fields. Our work entails comprehensive thermodynamic studies of new Kitaev materials in a wide parameter space in order to constrain the microscopic modelling of their exchange interactions. By shifting focus from the magnetically-ordered phases observed at low temperatures and low magnetic fields towards the vast “correlated paramagnetic” regions of their phase diagrams, we hope to gain a better phenomenological picture of their magnetic anisotropy and how it can lead to a quantum spin liquid.

Paschen, Silke

Strange metal heavy fermion compounds

Strange metals – best known for their linear-in-temperature electrical resistivity – are ubiquitous in various classes of strongly correlated electron systems. They can neither be described by the standard theory of metals, Fermi liquid theory, nor by the standard theory of quantum phase transitions, which is based on order parameter fluctuations. Heavy fermion compounds are particularly versatile model systems for studying this physics because they are comparatively simple, clean, and highly tunable [1]. This has led to the identification of several unique characteristics, most recently dynamical scaling of the optical conductivity [2] and strongly suppressed shot noise [3]. A unified theoretical description is in high demand. To boost progress, new tools need to be developed, and entanglement wittnesses seem to be an attractive option.

[1] S. Paschen and Q. Si, Nat. Rev. Phys. 3, 9 (2021).
[2] L. Prochaska et al., Science 367, 285 (2020).
[3] L. Chen et al., arXiv:2206.00673 (2022).

Pixley, Jedediah H.

Entanglement of the Kondo effect: its destruction and implication

This talk presents characterization of the Kondo effect in terms of its entanglement entropy. This is first discussed in terms of the impurity entanglement entropy, where the host degrees of freedom are traced out and the singlet nature of the Kondo effect, and its instability to non-trivial host density of states is understood. We will then discuss how we extended this calculation to compute the entanglement entropy a finite distance away from the impurity using the numerical renormalization group. This allows for a direct, real space visualization of the Kondo screening cloud, which is an additive and universal contribution to the entanglement on top of the conduction electron contribution (that is sizeable). We then show how the universal impurity entanglement becomes long range, extending across the entire system when the Kondo effect is destroyed. In the last part of the talk, we will utilize the notion of this additive entanglement entropy of the impurity model, and effectively “rotate away” the inactive orbitals in the conduction electrons to develop a much more efficient density matrix renormalization group approach to the problem that is expected to be broadly applicable beyond impurity models.

[1] J. H. Pixley et. al., Phys. Rev. B 91, 245122 (2015).
[2] C. Wagner, T. Chowdhury, J. H. Pixley, and K. Ingersent, Phys. Rev. Lett. 121, 147602 (2018).
[3] A.-K. Wu, M. T. Fishman, J. H. Pixley, E. M. Stoudenmire, arXiv:2212.09798 (2022).

Scheer, Elke

Gate control of supercurrents

Recently it has been observed that the supercurrent in nanoconstrictions and nanowires can be suppressed by applying voltages to a nearby gate electrode. The observations have been reproduced by different groups, but the mechanism behind the effect is under debate. In my talk I will briefly discuss the current state of research and possible explanantions as well as findiungs from our group obtained on unconventional superconductors.

Schuch, Norbert

Entanglement and topological order in many-body systems

Correlated quantum many-body systems can exhibit a wide range of exotic physical phenomena, such as topological order with anyonic excitations, which defy Landau's symmetry breaking paradigm. Their unconventional behavior is rooted in the complex quantum correlations present in these systems, leading to non-trivial ordering in their entanglement pattern. In my talk, I will explain how a description of such systems based on the structure of their entanglement can be used to reconcile their intricate global quantum correlations with local symmetry properties present in the entanglement of their local building blocks, and I will illustrate how this can provide us with new insights into the nature of these systems, and novel ways to probe their unconventional physics.

Serbyn, Maksym

Multilayer graphenes as a platform for superconductivity

In my talk I will discuss recent experiments on the superconductivity of trilayer ABC graphene and our explanation via Kohn-Luttinger mechanism. Motivated by these experiments, I will consider a broad family of multilayer graphene stackings, identifying the ABCA graphene as a most promising material for realization of topological p+ip superconductivity.

Walther, Philip

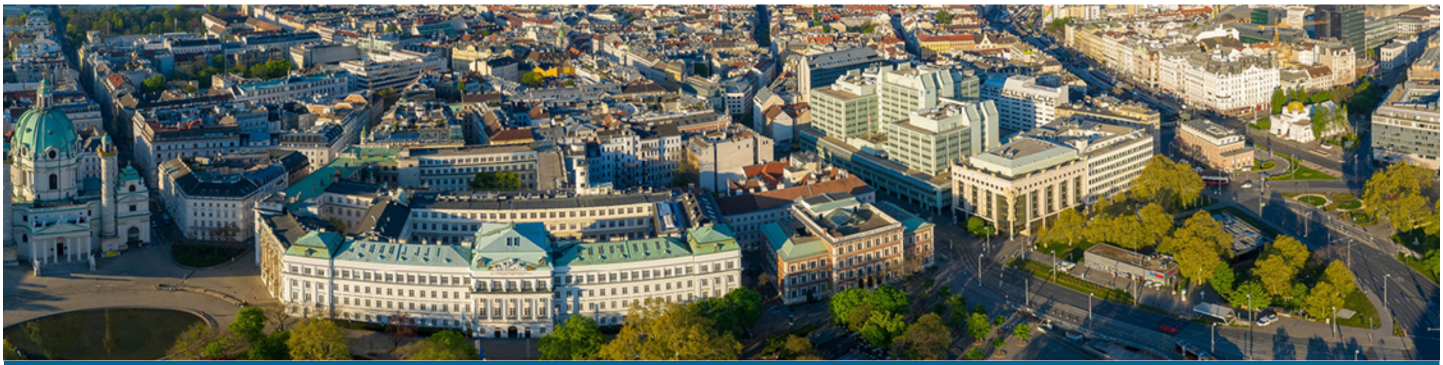
Photonic quantum computing – a bright future for many applications

Quantum photonics allows for a variety of quantum information applications. Here I will present that quantum photonics platforms show advantages for various quantum computations such as quantum machine learning and in particular reinforcement learning [1], in addition to secure quantum [2] and classical computing tasks [3,4] that require quantum networks. As outlook I will discuss technological challenges for the scale up of photonic quantum computers [5] and remarkable opportunities for special-purpose applications such as neuromorphic circuits [6].

[1] Nature 591, 229 (2021)
[2] npj Quantum Inf. 7, 25 (2021)
[3] Nature Comm. 9, 5225 (2018).
[4] npj Quantum Inf. 7, 98 (2021).
[5] Nature Nanotech. 16, 318 (2021).
[6] Nature Photon. 16, 318 (2022).

Locations

Wednesday, February 22, 2023	Thursday, February 23, 2023
TUtheSky Getreidemarkt 9, 1060 Wien 11th floor, room BA11B09	Kontaktraum Gußhausstraße 25-29, 1040 Wien 6th floor, room CD0603
https://tuw-maps.tuwien.ac.at/?q=BA11B09	https://tuw-maps.tuwien.ac.at/?q=CD0603



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Layout PR & Marketing
03/2022

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