Summer School 2023

Correlated Quantum Materials & Solid State Quantum Systems

www.q-ms.org

October 2-6, 2023

Institute of Science and Technology Austria (ISTA), Klosterneuburg

www.tuwien.at

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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 areas. Concepts and methods developed in the context of quantum information and computation will contribute to a better understanding of correlated quantum materials. For example, “entanglement meters” will be devised to unravel the mystery of the strange metal state. In turn, research will be conducted into how correlated quantum materials can be used for quantum applications. Correlated quantum materials with topological properties for instance could lead to very robust and well-controllable quantum devices in novel hybrid systems.

The Summer School 2023 on Correlated Quantum Materials & Solid State Quantum Systems is the first school of the SFB Q-M&S – a collaborative research project funded by the Austrian Science Fund (FWF) and the German Research Foundation (DFG), with 10 PIs hosted at 4 institutions in Austria and Germany. The school is primarily designed to train the SFB’s PhD students and postdocs, but it is also open to other researchers

Program

	9:00-10:00	10:00-11:00	Coffee break	11:30-12:30	Lunch	2:00-3:00	3:00-4:00	Coffee break	4:30-5:30	5:30-6:30	6:30-9:00
Mo. 2	E. Scheer	A. Tennant		N. Trivedi		Posters	Posters		Training (SFB juniors) Discussions	EB Meeting (SFB EB) Discussions	Dinner (SFB + lecturers)
Tu. 3	E. Scheer	A. Tennant		N. Trivedi		Lab tour Modic	D. Klammer S. Madsen		Posters	Posters	Discussions
We. 4	S. Paschen	J. Checkelsky		T. Nova		Lab tour Katsaros	N. Holmes		Discussions	Discussions	Discussions
Th. 5	T. Nova	J. Checkelsky		D. Natelson		F. Assaad	Hike		Hike	Hike	Dinner (optional)
Fr. 6	S. Paschen	D. Natelson		F. Assaad		Training (SFB juniors) Discussions	Training (SFB juniors) Discussions		Training (SFB juniors) Discussions	Closure	

Monday, October 2, 2023

Join us via Zoom: https://tuwien.zoom.us/j/68189380206?pwd=b3hIZ3lQeWVJc0syQnpNS3pNS21EQT09	
08:50-09:00	Opening
Chair:	Karsten Held
09:00-10:00 (45+15)	Elke Scheer, University of Konstanz *Introduction to quantum transport*
10:00-11:00 (45+15)	Alan Tennant, University of Tennessee, Knoxville *Entanglement in Condensed Matter*
11:00-11:30	Group photo and coffee break
11:30-12:30 (45+15)	Nandini Trivedi, Ohio State University *Quantum Magnetism: role of topology and strong correlations*
12:30-14:00	Lunch break
Chair:	TBC
14:00-16:00	Posters
16:00-16:30	Coffee break
16:30-17:30	Michael Traindt (SFB juniors) *Confident appearance in presentations* Individual discussions
17:30-18:30	SFB Executive Board Meeting (SFB Executive Board) Individual discussions
19:00-21:00	Opening dinner (SFB and lecturers) Redlingerhüte, https://www.redlingerhuette.at/ 3400 Kierling

Tuesday, October 3, 2023

Join us via Zoom: **https://tuwien.zoom.us/j/68189380206?pwd=b3hIZ3lQeWVJc0syQnpNS3pNS21EQT09**	
Chair:	Georgios Katsaros
09:00-10:00 (45+15)	Elke Scheer, University of Konstanz *Introduction to Mesoscopic Superconductivity*
10:00-11:00 (45+15)	Alan Tennant, University of Tennessee, Knoxville *Entanglement in Condensed Matter*
11:00-11:30	Coffee break
11:30-12:30 (45+15)	Nandini Trivedi, Ohio State University *Quantum Spin Liquids*
12:30-14:00	Lunch break
Chair:	TBC
14:00-15:00	Lab tour Modic (guided by Kimberly Modic)
15:00-15:30	Daniela Klammer, Institute of Science and Technology Austria *Equity, diversity, and inclusion (EDI) and career support at ISTA*
15:30-16:00	Stefanie Madsen, Technische Universität Wien *Early Career and Family-Work-Life-Balance Support at TU Wien*
16:00-16:30	Coffee break
16:30-18:30	Posters
18:30-21:00	Individual discussions

Wednesday, October 4, 2023

Join us via Zoom: **https://tuwien.zoom.us/j/68189380206?pwd=b3hIZ3lQeWVJc0syQnpNS3pNS21EQT09**	
Chair:	Maksym Serbyn
09:00-10:00 (45+15)	Silke Bühler-Paschen, Technische Universität Wien *Heavy fermion systems – From quantum criticality to electronic topology (1)*
10:00-11:00 (45+15)	Joseph Checkelsky, Massachusetts Institute of Technology *Quantum Materials Design: Magnetic, Topological, and Crystalline Flat Band Systems (1)*
11:00-11:30	Coffee break
11:30-12:30 (45+15)	Tobia Nova, ETH Zürich Harnessing *Terahertz Waves: Linear, Nonlinear and Quantum Approaches to Material Control (1)*
12:30-14:00	Lunch break
Chair:	TBC
14:00-15:00	Lab tour Katsaros (guided by Jaime Saez Mollejo)
15:00-16:00	Natasha Holmes, Cornell University *Teaching and learning in physics lab courses*
16:00-16:30	Coffee break
16:30-21:00	Individual discussions

Thursday, October 5, 2023

Join us via Zoom: **https://tuwien.zoom.us/j/68189380206?pwd=b3hIZ3lQeWVJc0syQnpNS3pNS21EQT09**	
Chair:	Fakher Assaad
09:00-10:00 (45+15)	Tobia Nova, ETH Zürich Harnessing *Terahertz Waves: Linear, Nonlinear and Quantum Approaches to Material Control (2)*
10:00-11:00 (45+15)	Joseph Checkelsky, Massachusetts Institute of Technology *Quantum Materials Design: Magnetic, Topological, and Crystalline Flat Band Systems (2)*
11:00-11:30	Coffee break
Chair:	Georgios Katsaros
11:30-12:30 (45+15)	Douglas Natelson, Rice University *A guide to (electronic) noise measurements in condensed matter physics*
12:30-14:00	Lunch break
14:00-15:00	Fakher F. Assaad, Julius-Maximilians-Universität Würzburg *Fermion Quantum Monte Carlo for heavy fermions and frustrated spin systems (1)*
15:00-18:00	Hike (guided by Reka Tatar)
18:00-21:00	Dinner / "Jause" (optional) Weingut Kerbl, https://weingutkerbl.at/ Raphael Donner-Gasse 19, 3400 Klosterneuburg

Friday, October 6, 2023

Join us via Zoom: **https://tuwien.zoom.us/j/68189380206?pwd=b3hIZ3lQeWVJc0syQnpNS3pNS21EQT09**	
Chair:	Neven Barišić
09:00-10:00 (45+15)	Silke Bühler-Paschen, Technische Universität Wien *Heavy fermion systems – From quantum criticality to electronic topology (2)*
10:00-11:00 (45+15)	Douglas Natelson, Rice University *Shot noise as a probe of unusual emergent excitations in condensed matter physics*
11:00-11:30	Coffee break
11:30-12:30 (45+15)	Fakher F. Assaad, Julius-Maximilians-Universität Würzburg *Fermion Quantum Monte Carlo for heavy fermions and frustrated spin systems (2)*
12:30-14:00	Lunch break
Chair:	TBC
14:00-16:00	J. Baumeister, Scienza Science Coaching (SFB juniors) *The Voice: Instrument for Scientists* Individual discussions
16:00-16:30	Coffee break
16:30-17:30	J. Baumeister, Scienza Science Coaching (SFB juniors) *The Voice: Instrument for Scientists* Individual discussions
17:30-17:45	Closure

Abstracts

Assaad, Fakher F.

Fermion Quantum Monte Carlo for heavy fermions and frustrated spin systems

In this first lecture I will briefly review the fermion Monte Carlo method and its application to heavy fermion system as described by a Kondo-Heisenberg lattice model. This approach maps the model onto a U(1) gauge theory. This formulation renders the classification of possible phases and phase transitions very transparent. I will then show that so called dimensional Kondo mismatch systems allow for the realization of Heavy fermion metals and their transitions to Kondo breakdown and magnetically ordered phases.

The negative sign problem inherent to quantum Monte Carlo approaches renders the computational effort exponential in lattice size and inverse temperature. But this does not mean that we cannot produce experimentally relevant results for specific model classes. It turns out that we can formulate the quantum Monte Carlo method to solve Kitaev models relevant for RuCl3 down to 40K. After comparing our model calculations to experimental results, I will show that the method can be generalized to include phonon degrees of freedom. The importance of such a generalization lies in the fact that the Debye temperature and magnetic exchange are in the same ballpark.

Bühler-Paschen, Silke

Heavy fermion systems – From quantum criticality to electronic topology

In the first lecture I will introduce basic concepts of heavy fermion systems, with a focus on phenomenology and experiments. I will also describe how the extreme tunability of the correlation strength that is characteristic of this materials class relates to quantum criticality, and introduce the concept of quantum criticality beyond the order parameter paradigm.

The second lecture will focus on heavy fermion compounds with nontrivial electronic topology, in particular the recently established class of Weyl-Kondo semimetals.

Checkelsky, Joseph

Quantum Materials Design: Magnetic, Topological, and Crystalline Flat Band Systems

In these lectures we discuss the design and synthesis of quantum materials with electronic correlation and non-trivial electronic topology. We focus on the role of magnetism and electronic band flattening to realize these effects. We also discuss practical tools for finding and realizing these materials as well as an outlook for future research directions.

Natelson, Douglas

A guide to (electronic) noise measurements in condensed matter physics

This talk is intended as a pedagogical introduction to electronic noise measurements, looking at the fluctuations in the current and/or voltage through a sample of interest. As we shall see, noise can convey considerably more information than the ordinary electronic transport measurement of current as a function of voltage. Different noise processes will be discussed, including Johnson-Nyquist noise (the equilibrium thermal noise that is an unavoidable consequence of thermodynamics), shot noise (the nonequilibrium “excess” noise that is a consequence of the granularity of charge carriers in materials), and “flicker” noise (actual temporal fluctuations in the resistance of a sample that can interfere with shot noise measurements). Various noise measurement techniques are discussed, including trade-offs associated with the different methods.

Shot noise as a probe of unusual emergent excitations in condensed matter physics

Electronic shot noise has proven to be an excellent tool for examining emergent charge-carrying excitations in condensed matter systems. In this talk I will describe three examples (two from my own laboratory) in which shot noise has revealed otherwise inaccessible information about the nature of current transport in strongly interacting quantum materials. Specific experiments to be discussed are: (very briefly) the observation of fractionally charged excitations in the fractional quantum Hall effect; the confirmation of electronic pairing above Tc and at energy scales large compared to the superconducting gap in copper oxide superconducting structures; and the observation of anomalously suppressed shot noise in wires made from a “strange” metal, evidence implying that well-defined quasiparticles don’t exist in this non-Fermi liquid system.

Nova, Tobia

Harnessing Terahertz Waves: Linear, Nonlinear and Quantum Approaches to Material Control

In the fascinating world of quantum materials, light-matter interactions play a pivotal role in revealing and controlling their exotic properties. These lectures provide a comprehensive look into contemporary methods harnessing both linear and nonlinear terahertz techniques and their role in the exploration and modification of quantum matter. Key topics include strong-field resonant and off-resonant terahertz control, the foundational concepts underpinning Floquet engineering, and the latest strategies surrounding cavity control of quantum materials. Through this discourse, participants will gain insight into how these techniques are not only advancing our fundamental understanding but also shaping potential applications in next-generation technologies.

Scheer, Elke

Introduction to quantum transport

In this lecture I will first remind of the most important facts about electronic properties of solids in reduced dimensions and the relevant intrinsic time, length, and energy scales. I will then introduce the basic concepts of electronic transport through quantum coherent conductors: Conductance quantization and the Landauer formula and exemplify its application for a model system described by a single electronic level.

Introduction to Mesoscopic Superconductivity

In this lecture I will introduce the fundamental concepts of transport phenomena at interfaces between superconductors and non-superconductors, i.e., Andreev reflection. Andreev reflection is the basic mechanism to convert superconducting charge carriers (Cooper pairs) into single quasiparticles and vice versa. I will then describe one of the most prominent phenomena resulting from Andreev reflection which is the proximity effect.

Tennant, Alan

Entanglement in Condensed Matter

In lecture 1 I will cover how entanglement arises in condensed matter systems and the idea of quantum entanglement witnesses. I will then cover key witnesses and their relation to experimental observables including proposed ways to measure these, especially using neutron scattering.

In lecture 2 I will cover the actual use of entanglement witnesses experimentally. How they can be used as part of protocols to identify quantum phases, and other concepts such as quantum correlators and the application of modal entanglement in probes.

Trivedi, Nandini

Quantum Magnetism: role of topology and strong correlations

1. How do strong correlations lead to quantum magnets?
2. When do they order?
3. When do they not? -> quantum spin liquids

Quantum Spin Liquids

1. Majorana Fermions
2. Gauge theory
3. Entanglement
4. Open questions

Location

Moonstone Building
Institute of Science and Technology Austria (ISTA)
Am Campus 1, 3400 Klosterneuburg

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Karlsplatz 13, 1040 Wien

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Photos TU Wien | Matthias Heisler/goemb.at
Layout PR & Marketing
03/2022

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