IMPRS-STNS Workshop on Frontiers in Quantum Materials

Ringberg, October 10-13, 2021

Max Planck Institute of Microstructure Physics
Weinberg 2 | 06120 Halle (Saale) | Germany

Aim of the Workshop

The **2021 IMPRS-STNS Workshop on Frontiers in Quantum Materials** takes place from **10th to 13th of October 2021** at **Ringberg Castle** at Tegernsee near Munich.

We invite you to lively discussions about new trends in quantum materials research within the groups participating in the retreat. The event programme consists of three focus groups:

Focus on Research: We want to take a birds-eye view on questions such as:

- What motivates our work?
- Why is it interesting, meaningful and impactful?
- What techniques and approaches do we employ and what are the capabilities and facilities at our disposal?

We are happy that we have multiple distinguished scientists joining our retreat. Beyond learning about their fantastic research, we hope that the workshop can serve as a platform to come up with new ideas and finding connecting points for new collaborations between the research groups.

Focus on Techniques: Here, we want to make room for more hands-on discussion, focusing on *what* we can do rather than *how* and *why*. Again, we hope to spark new collaboration in order to make most efficient use of our capabilities and do interesting research.

Focus on Learning: To spice things up, we'll have a complementary programme catered specifically towards early-stage researchers, including poster sessions, a graphical abstract competition, a Scientific PowerPoint Night, free time for networking and discussions about our research as well as life as PhD, PostDoc, PI or professor/director.

We trust that through your participation and your valuable contributions, the retreat will be very fruitful for everyone involved.

Start / End Time

Bus departure from Halle (in front of Weinbergmensa, Wolfgang-Langenbeck-Straße 3) is at 09:00 AM on Sunday, October 10, 2021. Please make sure to arrive in time. Departure from Hallmarkt is at 09:15 AM. Please contact Berthold Rimmler in case you are late! You have to wear a mask inside the bus!

We plan to start at around 5:30 PM with a first afternoon session of our workshop. Rooms will be available for check-in on arrival and coffee is waiting for you.

We end our workshop on October 13 after lunch. Please check-out till 9 AM as rooms need to be prepared for the new arrivals in the afternoon. Bus departure is foreseen for 1 PM.

Address | Info on Accommodation

Schloss Ringberg | Schlossstraße 20
83708 Kreuth
Phone: +49 (0)8022 27 90 | http://www.schloss-ringberg.de/contact
The **internet access code** is available in the reception hall.

Breakfast is served from 8-9 AM every day.

Munich Airport to Tegernsee Bahnhof (by Train/Taxi)

For your arrival/departure by public transportation please check the time table of "Deutsche Bahn" at https://www.bahn.com/en. Please exit at Tegernsee. Make sure that you board the part of the train going to Tegernsee and not to Lenggries. Train will be split on its way from Munich.

You can buy your ticket online, upon arrival at the vending machines or at the ticket counter before entering the S-Bahn area at the airport. Your destination is "Tegernsee Bahnhof" and the train ride takes approx. 2 hours.

Please use a taxi from the train station "Tegernsee" towards the castle. Taxi Jasinski can be reached by phone +49 (0)8022/95099.

Schedule

	10 October 2021	11 October 2021	12 October 2021	13 October 2021
09:00		**09:00 - 10:30** Hope Bretscher	**09:00 - 10:30** Judith Driscoll (online)	**9:00 - 11:00** Andrea Migliorini, Elena Derunova *(with coffee break)*
10:00		*Coffee break*	*Coffee break*	
11:00		**11:00 - 12:00** David Johnson (online)	**11:00 - 12:00** Judith Driscoll (online)	**11:00 - 12:00** Wrap-up
12:00		*Lunch*	*Lunch*	*Lunch*
13:00		*Free time*	*Free time*	*Bus departure*
14:00		**14:30 - 16:00** Georg Woltersdorf	**14:30 - 16:30** Discussion 4: Daniel Loss	
15:00				
16:00	*Arrival*	*Coffee break*	*Coffee break*	
17:00	*Coffee break* **17:30 - 18:30** Introduction, Organization	**16:30 - 18:45** Bernhard Keimer	**17:00 - 18:45** Poster Session	
18:00	*Dinner*			
19:00	**19:30 - 21:00** Inrgid Mertig	*Dinner*	*Dinner*	
20:00		**20:30 - 22:00** Graphical Abstract Competition	**20:30 - 22:00** Scientific PowerPoint Night	
21:00	**21:00 - 22:00** Poster Session + Get-together			

Legend:

(blue)	Focus on Research
(orange)	Focus on Techniques
(green)	Focus on Learning
(yellow)	From within MPI
(grey)	Organization

Transversal transport coefficients and topological properties

Ingrid Mertig

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Spintronics is an emerging field in which both charge and spin degrees of freedom of electrons are utilized for transport. Most of the spintronic effects—like giant and tunnel magnetoresistance—are based on spin- polarized currents which show up in magnetic materials; these are already widely used in information technology and in data storage devices.

The next generation of spintronic effects is based on spin currents which occur in metals as well as in insulators, in particular in topologically nontrivial materials. Spin currents are a response to an external stimulus—for example electric field or temperature gradient—and they are always related to the spin-orbit interaction. They offer the possibility for future low energy consumption electronics.

The talk will present a unified picture, based on topological properties, of a whole zoo of transversal transport coefficients: the trio of Hall, Nernst, and quantum Hall effects, all in their conventional, anomalous, and spin flavour. The formation of transversal charge and spin currents and their interconversion as response to longitudinal gradients is discussed.

Biographical Sketch

Ingrid Mertig
1974-1979 – Studies in physics, TU Dresden, Germany
1979 – Diploma Thesis in Theoretical Physics, TU Dresden
1982 – Ph.D. Thesis in Theoretical Physics, TU Dresden
1982-1985 – Assistant Professor, TU Dresden, Institute of Theoretical Physics
1985-1990 – Postdoc, Joint Institute for Nuclear Research, Russia
1985-1990 – Senior Scientist, Joint Institute for Nuclear Research, Russia
1995 – Habilitation in Theoretical Physics, TU Dresden
since 2001 – C4/W3 Professor, Martin Luther University Halle-Wittenberg, Germany

Terahertz with a twist: On-chip terahertz spectroscopy of moiré heterostructures

Hope Bretscher

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The enhanced control and new degrees of freedom enabled by van der Waals (vdW) heterostructures provide a new bottom-up approach to design macroscopic quantum phenomena in condensed matter systems. In vdW heterostructures, particularly those with moiré superlattices, a wide-variety of correlated and topological phases, including unconventional superconductivity, nematic phases, strange metals, and correlated insulators, have been observed. The characteristic energy scale of such phases is believed to be on the few meV energy (THz frequency) scale, making THz electrodynamical measurements vital for understanding the microscopic interactions underlying the phase diagram. However, wide-field THz spectroscopy is precluded by the typical microscopic size of vdW heterostructures, and conventional electronics cannot reach THz frequency scale.

In this talk, I will introduce and discuss the progress of on-chip THz spectroscopy, a near field technique that will enable the THz conductivity of microscopic heterostructures to be captured in conjunction with transport, and at millikelvin temperatures with strong magnetic fields. The THz response measured using this platform will encode important system parameters such as quasiparticle scattering rates, strength of electronic correlations, magnitudes of electronic energy gaps, eigenfrequencies of collective modes, and the density of superconducting carriers. This information will be integral for establishing design principles for vdW heterostructures, which in turn could further our understanding of more complex systems and outstanding challenges in condensed matter.

Biographical Sketch

Hope Bretscher grew up in Missouri, USA, before moving to the University of Chicago to study physics and human rights. To continue investigating the connection between these two fields, she crossed the Atlantic to pursue a master's degree in Science and Technology Studies in Edinburgh, Scotland, during which she focused on lead-acid battery recycling in India. She circled back to physics in 2016, when she started a PhD in the Optoelectronics Group at the University of Cambridge (under the supervision of Dr. Akshay Rao). Here, her research focused on the investigation of the optoelectronic properties of low-dimensional inorganic materials using visible, ultrafast spectroscopy techniques. She recently defended her PhD thesis, and has now joined the group of Dr. James McIver at the Max Planck Institute for the Structure and Dynamics of Matter in Hamburg, studying correlated phenomena in van der Waals heterostructures using on-chip THz spectroscopy.

Synthesis of Compounds with Designed Nanoarchitecture

David C. Johnson

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Major limitations to discovering new compounds include the lack of synthetic routes to compounds that are metastable and the challenge of predicting the energy landscape around both global and local free energy minima to assess synthesis approaches. The reactions between solids are typically diffusion limited, producing thermodynamic products as a result of high reaction temperatures and long reaction times. Fluid phase synthesis approaches are nucleation limited with high diffusion rates enabling a large part of the energy landscape to be explored. We have developed a third approach, controlled by nucleation but diffusion limited, based on controlling the composition of an amorphous intermediate on a nanoscale. The low diffusion rates limit the extent that the energy landscape is explored, enabling new compounds and heterostructures to be synthesized with nanoarchitectures templated by the precursor. What forms is the easiest structure to nucleate, which can be controlled by local composition and interfaces. Emergent properties (electrical, thermal and magnetic) vary systematically with nanoarchitecture. Our goal is to discover the design rules to predict how to make a targeted structure and to understand how and why emergent properties change with nanoarchitecture.

Biographical Sketch

David C. Johnson is the Rosaria Haugland Foundation Chair in Pure and Applied Chemistry at the University of Oregon. Johnson's research is at the interface of chemistry and physics focused on controlling materials properties using the nanoarchitecture of heterostructures. His non-traditional approach to chemical synthesis has led to many new materials with unprecedented physical properties, such as compounds with the lowest thermal conductivity ever reported for a fully dense solid. Johnson received his undergraduate education at Rutgers University, his Ph.D. from Cornell in 1983, and worked as a research chemist for DuPont before coming to the University of Oregon in 1986. He received an Office of Naval Research Young

Investigator award in 1987 and the Oregon Academy of Science's Outstanding Scientist Award in 2006. He has served as a Board Member for the International Thermoelectric Society and is a founding academic member of the Oregon Nanoscience and Microtechnology Institute ONAMI. He was a Mercator Fellow of the DFG (the German Research Foundation) in 2013 at the University of Freiburg. In 2019 he was honored by a Humboldt Research Award.

Imaging magnetic excitations from GHz to THz

Georg Woltersdorf

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First, I will briefly discuss the nature of spin wave excitations in ferromagnets. Next, a novel method for imaging of these waves is introduced. Specifically, we demonstrate coherent imaging of parametric spin wave generation by time-resolved magneto-optical microscopy. In addition it will be shown that the generated non-linear magnon modes can be stabilized by means of injection locking. In a second experiment we demonstrate the up-conversion of radio frequency excitations across up to six octaves using non-linear dynamics in NiFe at very low bias fields. As a next step we will examine spin waves in the THz frequency range that are excited by ultrashort spin current pulses. Finally, a novel method to generate intense current or field pulses that is based on the spin Hall effect will be discussed.

Biographical Sketch

Georg Woltersdorf studied physics in Halle and Sheffield (UK) from 1995 to 2001. Subsequently, he graduated from Simon Faser University (Canada) with a Ph.D. in physics in 2004. Following a postdoc appointment at the University of Regensburg (Germany), he worked as a research group leader and staff scientist at University of Regensburg. In 2013, he was appointed as a full professor at the Martin Luther University, Halle, Germany. His main research interests include spin dynamics, spin currents, and ultrafast phenomena in magnetic heterostructures and devices.

Spectroscopy of quantum materials

Berhard Keimer

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Why do some correlated metals become superconducting and others don't? How can we develop new superconductors with higher transition temperatures? These are the kinds of questions that drive our research. Our approach combines synthesis of high-quality crystals and thin-film structures, spectroscopic experiments (including particularly energy- and momentum-resolved probes), and close collaboration with theorists. Our goal is to develop quantitatively predictive theories that guide the synthesis of new materials. We will briefly discuss some examples of our current research.

Biographical Sketch

Bernhard Keimer
1985 – Pre-diploma in Physics, Technical University of Munich
1991 – Ph.D. in Physics, Massachusetts Institute of Technology
1991-1992 – Research Associate, Massachusetts Institute of Technology
1992-1996 – Assistant Professor of Physics, Princeton University
1996-1997 – Associate Professor of Physics, Princeton University
1997-1998 – Full Professor of Physics, Princeton University
since 1998 – Director, Max Planck Institute for Solid State Research / Honorary Professor, University of Stuttgart
since 2020 – Adjunct Professor, University of British Columbia, Canada

Making Oxide Thin Films and Heterostructures More Perfect

Judith MacManus-Driscoll

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Functional oxides for basic electronic devices or for quantum applications promise so much. However, to date, they've not lived up to the promise as much as they could/should. A key reason is because of the presence of intrinsic and extrinsic defects, the latter of which exacerbate extrinsic defects. Current thin film deposition routes mostly cannot deliver the required perfection and performance. This talk looks at some of the reasons for the current challenges and suggests possible ways (with examples) to potentially improve perfection.

Biographical Sketch

Judith Driscoll is Professor in the Materials Science at the University of Cambridge, and is Royal Academy of Engineering Chair in Emerging Technologies. She researches nanostructured oxide thin films for low energy electronics and energy applications. She has wide experience across nearly all the functionalities of oxides and she has a particular focus on engineering oxides to suit particular applications.

From Fractional Spin to Topological Magnons

Daniel Loss

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[*TBA*]

Biographical Sketch

Daniel Loss – quantum condensed matter theorist, pioneer in the field of spintronics, magnonics, and quantum computing in semiconducting platforms. Daniel Loss received Diploma and Ph.D. in Theoretical Physics at the University of Zürich in 1983 and 1985, resp., where he stayed for four more years. sFrom 1989 to 1991 he worked in Urbana (USA), with Nobel Laureate A. J. Leggett, and from 1991 to 1993 at IBM, Yorktown Heights (USA). In 1993 he moved to Vancouver to become Assistant and then Associate Professor at SFU. In 1996 he returned to Switzerland to become Full Professor of Theoretical Physics at the University of Basel. In 2005 he became director of the Basel Center for Quantum Computing and Quantum Coherence (QC2), in 2020 co-director of the national center 'NCCR SPIN' on spin-based quantum computing in semiconductors, in 2012 team leader at CEMS RIKEN (Tokyo). Since 2021 External Scientific Member of the Max Planck Society at MPI Halle, 2014 Member of the German National Academy of Sciences Leopoldina, 2013 Member of the European Academy of Sciences, and 2000 Fellow of the American Physical Society. Awards: King Faisal International Prize in Science 2017, Blaise Pascal Medal in Physics 2014, European Academy of Sciences, Marcel Benoist Prize 2010 (most prestigious science prize in Switzerland), Humboldt Research Prize 2005. Daniel Loss has more than 550 publications with over 53000 citations and an h-index of 100.

Racetrack memory - material challenges and prospects

Andrea Migliorini

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The exponential growth of global data traffic and the increasing gap between processors and memories in terms of operating speed, energy consumption, performance and scalability, have dramatically boosted the demands for advanced, non-volatile memories with larger data capacity, higher operation speed and lower energy consumption. One of the most promising candidates for the fulfilment of future memories requirements is the Race-Trak Memory (RTM). Originally proposed in 2008, RTM is a shift register memory consisting in a magnetic nanowire, in which the information bits are stored as magnetic domains that can be efficiently displaced along the nanowire upon application of electrical current pulses. Over the last decade, RTM has attracted great scientific interest, resulting in the discovery of many important material classes and physics. These findings paved the way for energetically more efficient and functionally richer RTM devices, which are desirable for future spintronic memory applications.

In this talk, I will briefly re-visit the development history of RTM and summarize recent important discoveries, with particular focus on novel materials and applications. Then, I will discuss the key prospects and challenges for the success of RTM.

How the solved Millennium problem can lead to AI search of quantum materials

Elena Derunova

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A few years ago the story of the Millennium problem's proof with denial of the actual award attracted lots of interest to the modern topology and geometry. The proved Poincare conjecture was considered as the finding of a shape of the universe. However, it was thought only in relation to the real space shape. In quantum material science, there's another space more important with regards to transport properties – reciprocal space.

In my talk, I show how distribution of energy in reciprocal space (i.e. a bandstructure) makes reciprocal space "curved" similar to how mass makes curved real space in general relativity. This way the set of topologically connected bands form a manifold, which can be classified in one of the 8 Thurston geometries (as it was proved for Poincare conjecture). Each geometry then corresponds to a distinct quantum transport effect and the geodesic equations on the manifold can quantify the effect instead of semiclassical transport. This computational approach is straightforward, and therefore after appropriate theory is built, this method can be run automatically over crystallographic databases (e.g. materialsproject) to predict desired for industry transport phenomena. This also gives enough dataset to train a neural network and make AI predict the class of compounds or not yet existing compounds to search for the needed transport effect as I will briefly discuss in my talk.

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