

# QMA Retreat

## *Topological Quantum Matter 2023*

September 25 - 27, 2023

Penta Hotel in Leipzig



**ct.qmat**

**Complexity and Topology  
in Quantum Matter**

Monday, September 25	
11:00 - 12:00	Arrival
12:00 - 14:00	Lunch
14:00 - 14:10	Welcome note from organisers
14:10 - 14:30	Introduction to QMA/ct.qmat by Matthias Bode
14:30 - 15:30	<b>Manfred Sigrist</b> “ <i>Unconventional Superconductivity - Aspects of Symmetry and Topology</i> ”
15:30 - 15:50	Coffee Break
Session 1: Topology	
15:50 - 16:10	Jonas Erhardt, JMU Würzburg “ <i>Bulk Signatures of Topology in a QSH Insulator Probed by Circular Dichroism in ARPES</i> ”
16:10 - 16:30	Maximilian Ünzelmann, JMU Würzburg “ <i>Tomography of Orbital Pseudospin Vortex Lines in a Topological Semimetal</i> ”
16:30 - 16:50	Alexander Fritzsche, JMU Würzburg “ <i>Strain Induced Curvature in a Driven Photonic Topological Insulator</i> ”
16:50 - 17:45	Ice Breaker Activity
18:30 - 19:30	Dinner
19:30 –	Fire-Place Chat with Jan Budich (TU Dresden) and Louis Veyrat (IFW Dresden)

Tuesday, September 26	
07:00 - 08:30	Breakfast
Session 2: Quantum Materials	
08:30 - 08:50	Kristian Tyn Kai Chung, MPI-PKS Dresden “ <i>2-Form <math>U(1)</math> Spin Liquids: Classical Model and Quantum Considerations</i> ”
08:50 - 09:10	Matteo Dürrnagel, JMU Würzburg “ <i>From Ab-Initio Bandstructures to Correlated Phases of Matter: Renormalization Group Approaches to Interacting Electron Systems</i> ”
09:10 - 09:30	Georgia Fragkopoulou, TU Dresden “ <i>Bond Disorder in the High-Field Eegime of Extended Heisenberg-Kitaev Models</i> ”
09:30 - 09:45	Coffee Break
09:45 - 10:45	<b>Wolf Widdra</b> “ <i>Electron-Phonon Coupling at Perovskite Oxide Interfaces</i> ”
10:45 - 11:00	Break

<b>Session 3: Quantum Materials</b>	
11:00 - 11:20	Gohil Takhur, TU Dresden “ <i>Pb<sub>9</sub>Cu(PO<sub>4</sub>)<sub>6</sub>O</i> : Superconducting or Not?”
11:20 - 11:40	Nora Taufertshöfer, JMU Würzburg “ <i>Competing Phases in AlAs Quantum Wells</i> ”
11:40 - 12:30	Poster Teaser Presentations
12:30 - 14:00	Lunch
14:00 - 14:10	Group Photo Session
14:10 - 18:30	Social Activities
18:30 - 20:00	Dinner
20:00 –	Poster Session

<b>Wednesday, September 27</b>	
07:00 - 08:30	Breakfast
<b>Session 4: Topology</b>	
08:30 - 08:50	Haipeng Sun, JMU Würzburg “ <i>Magnetic Topological Transistor Exploiting Layer-Selective Transport</i> ”
08:50 - 09:10	Viktor Könye, IFW Dresden “ <i>Effective Non-Hermitian Topology in Multi-Terminal Devices</i> ”
09:10 - 09:30	Niklas Wagner, JMU Würzburg “ <i>Green’s Function Zeros, Spinons and Topology</i> ”
09:30 - 09:45	Coffee Break
<b>Session 5: Hall-Effect</b>	
09:45 - 10:05	Christopher Fuchs, JMU Würzburg “ <i>Limits of the Early Onset Quantum Hall Effect in Paramagnetic (Hg,Mn)Te Quantum Wells</i> ”
10:05 - 10:25	Evgenii Maltsev, IFW Dresden “ <i>Anomalous Hall Effect in EuSn<sub>2</sub>As<sub>2</sub> Thin Flakes</i> ”
10:25 - 10:45	Leonid Bovkun, JMU Würzburg “ <i>Tuning the Band Structure for Narrowgap HgTe QWs with Cd-Doping</i> ”
10:45 - 11:00	Break
11:00 - 12:00	Election for QMA Representatives, Evaluation of the Poster Award, Evaluation of the Talk Award, Closing Remarks
12:00 - 14:00	Lunch

# List of Poster Contributions I

<b>P1</b>	Ankit Kumar, IFW Dresden, Germany Quantum Transport Properties of the Superconducting Weyl Semimetal
<b>P2</b>	Christian Niclaas Saggau, IFW Dresden, Germany 2D High Temperature Superconductor Integration in Contact Printed Circuit Boards
<b>P3</b>	Clara Johanna Lapp, TU Dresden, Germany Flat Bands of Surface States in Chiral Symmetric Superconductors
<b>P4</b>	Fabian Jakubczyk, TU Dresden, Germany The Superconducting Symmetries of $\text{CeRh}_2\text{As}_2$
<b>P5</b>	Yu Wang, JMU Würzburg, Germany Observation of Zero Energy States of 1D Gadolinium Chains on Nb(110) Superconducting Surface
<b>P6</b>	Abdul-Vakhab Tcakaev, JMU Würzburg, Germany Intermixing-Driven Surface and Bulk Ferromagnetism in the Quantum Anomalous Hall Candidate $\text{MnBi}_6\text{Te}_{10}$
<b>P7</b>	Gabriele Naselli, IFW Dresden, Germany Magnetic Warping in Topological Insulators
<b>P8</b>	Manaswini Sahoo, IFW Dresden, Germany Direct Observation of Mn Anti-Site Sublattice Coupling and its Distinct Ordering Transition in Magnetic Topological Insulator Candidates
<b>P9</b>	Maria Herz, TU Dresden, Germany Bismuth-Rich Intermetallic Rods
<b>P10</b>	Shailja Sharma, IFW Dresden, Germany Insights Into the Electronic Properties of Doped Topological Insulators: $\text{Bi}_2\text{Se}_3$ and $\text{Bi}_2\text{Te}_3$
<b>P11</b>	Tatiana Aureliia Uaman Svetikova, HZDR Dresden-Rossendorf, Germany Efficient THz Third Harmonic Generation in Topological HgTe Quantum Wells
<b>P12</b>	Wilhelm Krüger, TU Dresden, Germany Triple-Q Order in $\text{Na}_2\text{Co}_2\text{TeO}_6$ from Proximity to Hidden-SU(2)-Symmetric Point
<b>P13</b>	Daniel Lozano-Gómez, TU Dresden, Germany Entropically-Driven Spin-Liquid to Spin-Liquid Thermal Crossover in a Pyrochlore Magnet

# List of Poster Contributions II

<b>P14</b>	Jonas Schwab, JMU Würzburg, Germany
	Research Data Management Services for All of ct.qmat
<b>P15</b>	Anja Wenger, JMU Würzburg, Germany
	Thermal Transport in Weakly Coupled Spin-1/2 Heisenberg Ladders
<b>P16</b>	Richard Strunck, JMU Würzburg, Germany
	The VQE Algorithm for the Kagome Heisenberg Model
<b>P17</b>	Jiang Qu, IFW Dresden, Germany
	Metal-Assisted Mechanical Exfoliation of 2D Material Monolayers
<b>P19</b>	Shiyu Huang, JMU Würzburg, Germany
	Light-Matter Interaction of TMDCs in an Open Cavity
<b>P20</b>	Pampa Sadhukhan, JMU Würzburg, Germany
	Electronic and Transport Properties of Strained SrNbO <sub>3</sub> Thin Films on SrTiO <sub>3</sub> (001)
<b>P21</b>	Zihong Liu, JMU Würzburg, Germany
	Disorder Operator and Rienyi Entanglement Entropy of Symmetric Mass Generation
<b>P22</b>	Gabriel Rein, JMU Würzburg, Germany
	A Toy Model to Investigate the Role of Topology in Quantum Phase Transitions
<b>P23</b>	Adrien Reingruber, JMU Würzburg, Germany
	Interaction-driven Boundary Effects in Hydrodynamic Flow of Electrons in Finite Sized Graphene Sheets
<b>P24</b>	Fabian Richter, JMU Würzburg, Germany
	Non-Hermiticity and Parity-Time Symmetry at X-Ray Wavelengths
<b>P25</b>	Helene Müller, JMU Würzburg, Germany
	Superfluid Density of Non-Hermitian Superconductors
<b>P26</b>	Changan Li, JMU Würzburg, Germany
	Hybrid Higher-Order Skin-Topological Effect in Hyperbolic Lattices
<b>P27</b>	Jakob Lindenthal, TU Dresden, Germany
	Multi-Layer Laser-Structured Dielectric Systems for Photonic Transport

# List of Poster Contributions III

<b>P28</b>	Lorenzo Crippa, JMU Würzburg, Germany
	Exceptional Points in Strongly Correlated Materials: Spontaneous Symmetry Breaking and Charge Response
<b>P29</b>	Jakub Schusser, JMU Würzburg, Germany
	Intensity Asymmetries in Photoemission
<b>P30</b>	Jonathan Sturm, JMU Würzburg, Germany
	Topological Quantum Optics in Atomic Emitter Arrays
<b>P31</b>	Simon Widmann, JMU Würzburg, Germany
	Acoustic Inclined 2D SSH Model
<b>P32</b>	Marco Dittmar, JMU Würzburg, Germany
	Fermi Level Tuning of a $\text{MnBi}_2\text{Te}_4$ Monolayer
<b>P33</b>	Muthu Prasath Thirugnanasambandam Masilamani, JMU Würzburg, Germany
	One-Step Model Photoemission Calculations of Type-II Dirac Semimetal $\text{PtTe}_2$
<b>P34</b>	Nicolai Taufertshöfer, JMU Würzburg, Germany
	Growth and Spectroscopy of Thin Tellurium Films on Pt(111)
<b>P35</b>	Himanshu Lohani, JMU Würzburg, Germany
	Electronic Structure Evolution of Magnetic Weyl Semimetal $\text{Co}_3\text{Sn}_2\text{S}_2$ by Doping and Temperature
<b>P36</b>	Johannes Heßdörfer, JMU Würzburg, Germany
	Emergence of Surface States on the Topologically Dark Surface of a Layered Weak 3D Topological Insulator
<b>P37</b>	Wun-Chang Pan, JMU Würzburg, Germany
	STM Growth Studies of 5,14-ol-5,14-diborapentacyclo on Low-Index Coinage Metal Surfaces
<b>P38</b>	Markus Leisegang, JMU Würzburg, Germany
	The Molecular Nanoprobe Ballistic Transport With Atomic Precision
<b>P39</b>	Andreas Christ, JMU Würzburg, Germany
	Anisotropic Coupling of Individual Vibrational Modes to a Cu(110) Substrate
<b>P40</b>	Titouan Charvin, IFW Dresden, Germany
	Ballistic Transport of Dirac Fermions in 3D Topological Insulator Quantum Wires

# Manfred Sgrist

Professor at the Institute for Theoretical Physics of ETH Zürich,  
Switzerland

## *“Unconventional Superconductivity - Aspects of Symmetry and Topology”*

14:30 - 15:30 Monday, September 25

Unconventional superconductivity typically emerges in materials with strong electron correlations, frequently in close proximity of magnetic instabilities. This lecture aims to elucidate the main distinctions between conventional and unconventional superconductors. Theoretical considerations underline the pivotal significance of symmetry, offering insights that guide experimental investigation to identify the nature of a superconducting phase. Some further exotic features arise if unconventional superconductors are topologically non-trivial.

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# Wolf Widdra

**Professor at Martin-Luther-Universität, Halle-Wittenberg, Institute of  
Physics, Halle, Germany**

Prof. Wolf Widdra did his Ph.D. in experimental physics in 1991 at the University of Marburg, Germany. In 1992, he received prestigious Feodor Lynen Research Fellowship and subsequently, he joined as a postdoctoral fellow at UC Santa Barbara, California, USA for two years. Then, he moved back to Germany in TU Munich where he received habilitation in experimental physics in 2001. Afterwards, he joined as a Professor at TU Berlin and Max-Born Institute for Nonlinear Optics and Ultrafast Spectroscopy, Berlin, Germany for three years. Since 2003 until today he holds the position of Professor at Martin-Luther-Universität in experimental surface science. He has been Max Planck Fellow from 2010 in Max Planck institute for Microstructure Physics, Halle.

Prof. Widdra's research area includes the study of the surface and interface of oxide thin films, two-dimensional quasicrystals, phason dynamics of oxide quasicrystals, ultrafast spin dynamics and coupling of electron, phonon and spin degrees of freedom on ultrafast time scales. He is an expert in a broad spectrum of techniques like scanning tunneling microscopy, angle-resolved photoemission spectroscopy, laser-based two-photon photoemission, high-resolution inelastic electron scattering etc. His research group has discovered oxide quasicrystals.

The observation of unexpected two-dimensional transport properties at surfaces and interfaces of oxide perovskites with otherwise large bandgaps, as e.g., for SrTiO<sub>3</sub> and KTaO<sub>3</sub>, opened a wide field for fundamental physics and applications these properties arise from the formation of a two-dimensional electron gas (2DEG) at the interface. For transport and the electron-hole pair excitations at the 2DEG, the coupling of the excitations with low-energy phonons and phonon polaritons is essential.

Here I will discuss the low-energy excitations of the bare SrTiO<sub>3</sub>(001) and KTaO<sub>3</sub>(001) surfaces and will compare them with excitations in the presence of 2DEGs with variable charge carrier concentrations. By surface vibrational spectroscopy (high-resolution electron energy loss spectroscopy, HREELS) we identify three well-defined surface phonon polaritons for the bare perovskite surfaces. Different 2DEG states are prepared on SrTiO<sub>3</sub>(001) and KTaO<sub>3</sub>(001) either by annealing



under ultrahigh vacuum condition or by growth of an ultrathin layers of EuO on top. With formation of these 2DEGs, the discrete surface phonon polaritons couple to the electron-hole pair continuum as is witnessed by a substantial line broadening and asymmetric Fano-like line shapes. A quantitative description will be presented that accounts for all details of the line shape and paves the way for an in-situ analysis of the 2DEG charge carrier dynamics.

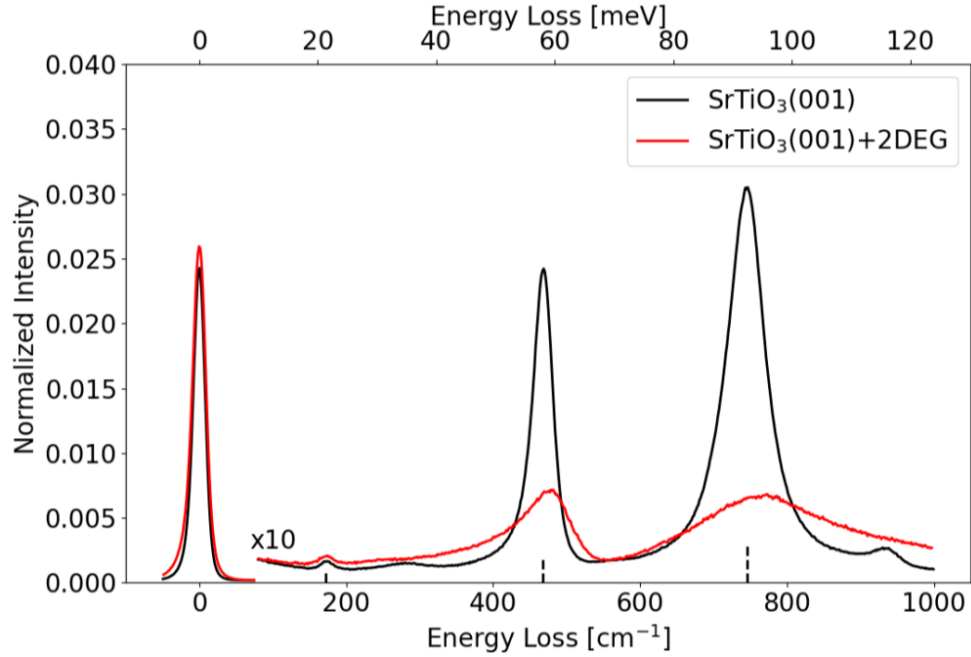


Figure 1: Vibrational spectra (HREELS) of SrTiO<sub>3</sub>(001) without (black line) and with presence of a 2DEG (red line). The three fundamental dipole-active surface phonon modes are marked, which broaden asymmetrically by 2DEG electron-phonon coupling.

- [1] A. F. Santander-Syro et al., *Nature*, 2011, 469, 189
- [2] J. Varignon, L. Vila, A. Barthélémy, and M. Bibes, *Nat. Phys.*, 2018, 14, 322
- [3] L. M. Vicente-Arche et al., *Adv. Mat.*, 2021, 33, 2102102

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# Jonas Erhardt

JMU Würzburg

*“Bulk Signatures of Topology in a QSH Insulator Probed by Circular  
Dichroism in ARPES”*

15:50 - 16:10 Monday, September 25

Indenene, a monolayer of In atoms arranged in a triangular lattice on SiC(0001), has recently been identified as a quantum spin Hall insulator (QSHI) [1]. Its topological character is encoded in a characteristic energy staggering of its orbital angular momentum (OAM) polarized Dirac states [1]. This makes indenene an ideal test case for recent claims that circular dichroism in angle-resolved photoelectron spectroscopy (CD-ARPES) gives access to local Berry curvature signatures via the OAM [2]. However, a particular challenge of such experiments is the extraction of the intrinsic OAM-related CD signal, requiring its distinction from final state effects and extrinsic contributions induced by experimental geometry. In this talk, I will present a systematic photon energy dependent CD-ARPES study of indenene’s Dirac states and use simple geometric considerations to disentangle experimental from OAM induced CD. The resulting OAM sequence confirms indenene to be a QSHI and thus establishes a new approach to experimentally identify the topological character of a 2D quantum material directly from its bulk states.

[1] M. Bauernfeind et al., Nat. Commun., 12, 5396 (2021)

[2] M. Schüler et al., Sci. Adv., 6, 2730 (2020)

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# Maximilian Ünzelman

JMU Würzburg

## *“Tomography of Orbital Pseudospin Vortex Lines in a Topological Semimetal”*

16:10 - 16:30 Monday, September 25

The geometric structure of Bloch wave functions in a periodic lattice may host topological defects, underpinning the unique properties of topological quantum matter. Here we report on the discovery of orbital vortex lines (OVL) in the three-dimensional (3D) band structure of a topological semimetal, TaAs. Leveraging dichroic photoemission tomography, we directly observe vortices of atomic orbital angular momentum (OAM) and trace their trajectories in full 3D momentum space. In the vortex core we observe an almost movable, two-fold spin-degenerate Weyl nodal line, a hitherto experimentally elusive topological excitation predicted in certain non-symmorphic crystals. Our results provide the first imaging of non-trivial quantum-phase winding at line nodes with profound consequences for the study of novel band topologies in metals.

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# Alexander Fritzsche

JMU Würzburg

*“Strain Induced Curvature in a Driven Photonic Topological Insulator”*

16:30 - 16:50 Monday, September 25

The research on topological states of matter has mainly focused on Euclidean or flat lattice geometries. Only very recently, topological phenomena in negatively curved or Hyperbolic lattices have attracted significant attention and Hyperbolic lattice tilings were studied especially in electronic circuits and circuit QED. In this talk, a different approach to Hyperbolic geometries is presented which can be applied in optical systems such as photonic waveguides or fiber loop setups. In a strained topological periodically driven lattice, we simulate a pseudomagnetic field as well as negative Gaussian curvature allowing us to move smoothly from Euclidean to Hyperbolic space and tune the curvature continuously. In this talk we explore the interplay between this curvature and the topology of the driven system and discuss phenomena unobserved in Euclidean lattice geometries.

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# Kristian Tyn Kai Chung

MPI-PKS Dresden

## “2-Form $U(1)$ Spin Liquids: Classical Model and Quantum Considerations”

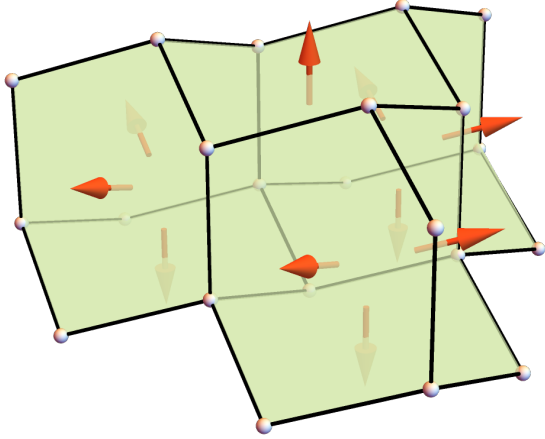
08:30 - 08:50 Tuesday, September 26

To this day, quantum spin ice remains perhaps the most important example of a quantum spin liquid in three dimensions, owing to (i) the plethora of pyrochlore compounds which might realize this phase, and (ii) the detailed theoretical understanding of the classical nearest-neighbor spin ice (NNSI) model and how quantum perturbations of this model can be mapped to a  $U(1)$  lattice gauge theory. In this talk, I propose the existence of a new class of gapless spin liquids in three dimensions: 2-form  $U(1)$  quantum spin liquids. To illustrate this phase, we first introduce a minimal classical Ising model on the pyrochlore lattice, analogous to nearest-neighbor spin ice (NNSI), which we dub the *spin vorticity model*, constructed to enforce a local “zero-curl” constraint on every hexagonal loop of the lattice.

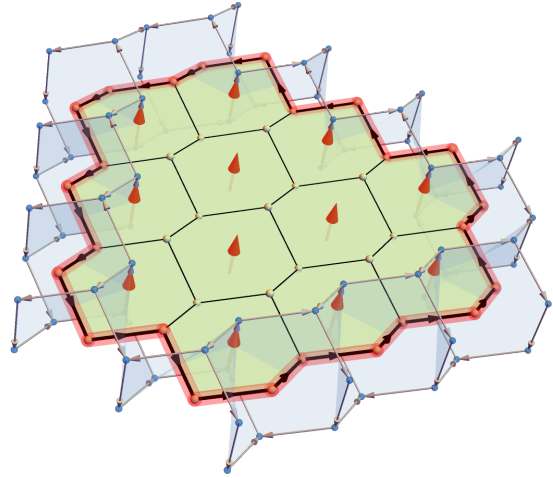
We demonstrate using analytic approximation and numerical Monte Carlo simulations that this model has an extensive ground state entropy and a low-temperature Coulomb-like phase characterized by “inverted” pinch point singularities in spin-spin correlation cross sections. We give a detailed characterization of the emergent gauge structure of the ground state manifold of this model, which may be described as a *condensate of membranes*—flipping a collection of spins forming a closed surface (Fig. 1a) costs zero energy.

Unlike established spin liquids like NNSI, this model contains no point-like quasi-particle excitations. Instead, the fractionalized excitations are extended string objects, created by flipping a collection of spins forming an open surface (Fig. 1b). At finite temperature, the classical model is then described by a gas of string loops in a background of fluctuating membranes. This Coulomb phase is described within the formalism of 2-form electrodynamics, where a 2-form  $U(1)$  gauge field couples to electrically charged strings. We then introduce a minimal quantum extension of the classical spin vorticity model, from which we derive an effective *membrane exchange* model of the quantum dynamics within the classical ground state manifold. This model maps directly to a frustrated 2-form  $U(1)$  lattice gauge theory. We further demonstrate how to quantize the string excitations, by coupling a 1-form *string field* to the emergent 2-form  $U(1)$  gauge field, thus mapping a spin model to a 2-form

gauge-Higgs model. We discuss the stability of the gapless deconfined phase of this gauge theory, and thus the possibility of realizing a novel phase of quantum matter: a 2-form  $U(1)$  quantum spin liquid.



(a) Flipping a collection of spins (red arrows) forming a closed surface costs zero energy.



(b) Flipping spins forming an open surface creates a string excitation on the boundary.

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# Matteo Dürrnagel

JMU

*“From Ab-Initio Bandstructures to Correlated Phases of Matter:  
Renormalization Group Approaches to Interacting Electron Systems”*

08:50 - 09:10 Tuesday, September 26

One of the central motifs of theoretical condensed matter physics is the understanding of underlying ordering mechanisms leading to spontaneous symmetry breaking in superconductors, magnets, and charge ordered phases. In this talk we review two important numerical tools to analyze Fermi surface instabilities based on the renormalization group approach: While functional renormalization group (fRG) provides an unbiased interplay of all kinds of electronically mediated ordering tendencies in a system, the random phase approximation (RPA) focuses on collective excitations as driving force of a symmetry breaking instability. We give an educational introduction to both methods centered around the extended capability and applicability unlocked by recent methodological progress. In particular, an exemplary workflow is presented to link experimental observations to a low energy effective microscopic theory in a numerically controlled way, that allows for description, prediction and correct interpretation of experimental observations.

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# Georgia Fragkopoulos

TU Dresden

*“Bond Disorder in the High-Field Regime of Extended  
Heisenberg-Kitaev Models”*

09:10 - 09:30 Tuesday, September 26

We study the effect of defects on extended Heisenberg-Kitaev models on the honeycomb lattice. Here we focus on bond disorder in the high-field regime of models relevant to  $\alpha$ -RuCl<sub>3</sub>. Within the spin-wave approach, clean models can have a polarized phase with gapped magnon excitations above the critical field. Our main result is an intermediate field regime, above the bulk critical field, that hosts impurity-induced textures and in-gap states. At a finite impurity concentration, symmetry breaking may turn this intermediate field regime to a precursor of the low-field ordered phase and in-gap states become impurity bands that lie inside the bulk gap.

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# Gohil Takhur

TU Dresden

*“ $Pb_9Cu(PO_4)_6O$ : Superconducting or Not”*

11:10 - 11:20 Tuesday, September 26

Superconductivity have enchanted mankind for over a century since its discovery in 1911 by H. K. Onnes. Since then, researchers have constantly made efforts to achieve superconductivity at room temperature anticipating to bring a disrupt in the existing technology. A very recent claim of room-temperature SC in a Cu doped Pb-apatite named as 'LK-99' by Lee, et al, created a tremendous sensation leading to numerous efforts made by the research community to replicate this effect. However, there have been considerable doubts over the claim as not many (read none) of the groups observed a zero resistance state or a room-temperature magnetic levitation as claimed in the original work of Lee et al. Additionally, there is a wide spread in the experimental data observed among samples synthesized by different groups, some observing metallic conduction, insulating or semiconducting behavior while some even observing a diamagnetic or ferromagnetic state in the sample. Hence, no consensus on the ground state of this material can reached until now. Here we discuss the results of the efforts made by our group to attempt to synthesize a phase pure LK-99 material through various routes and comment on the chemical and physical aspects leading to the absence of superconductivity.

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# Nora Taufertshöfer

JMU

## *“Competing Phases in AlAs Quantum Wells”*

11:20 - 11:40 Tuesday, September 26

As a material with multi-pocket fermiology GaAs/AlAs heterostructures may exhibit gate-tunable unconventional superconductivity arising from inter-pocket scattering. Starting from an ab initio band structure of an AlAs quantum well we study this possibility within the random phase approximation and investigate the interplay of the superconducting instability with the experimentally observed spin and valley polarized phases [1]. We compare our results to theoretical approaches on the two component 2D electron gas [2].

[1] O. Gunawan et al.: Spin-valley phase diagram of the two-dimensional metal-insulator transition, Nature Physics 3 (2007)

[2] A. Chubukov and S. Kivelson: Superconductivity in engineered two-dimensional electron gases, Phys. Rev. B 96, 174514 (2017)

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# Haipeng Sun

JMU

## *“Magnetic Topological Transistor Exploiting Layer-Selective Transport”*

08:30 - 08:50 Wednesday, September 27

We propose a magnetic topological transistor based on  $\text{MnBi}_2\text{Te}_4$ , in which the “on” state (quantized conductance) and the “off” state (zero conductance) can be easily switched by changing the relative direction of two adjacent electric fields (parallel vs. antiparallel) applied within a two-terminal junction. We explain that the proposed magnetic topological transistor relies on a novel mechanism due to the interplay of topology, magnetism, and layer degrees of freedom in  $\text{MnBi}_2\text{Te}_4$ . Its performance depends substantially on film thickness and type of magnetic order. We show that “on” and “off” states of the transistor are robust against disorder due to the topological nature of the surface states. Our work opens an avenue for applications of layer-selective transport based on the topological van der Waals antiferromagnet  $\text{MnBi}_2\text{Te}_4$ .

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# Viktor Könye

IFW Dresden

*“Effective Non-Hermitian Topology in Multi-Terminal Devices”*

08:50 - 09:10 Wednesday, September 27

Reflection matrices describing waves reflected from the boundaries of topological insulators exhibit non-Hermitian topological signatures. Based on this, we propose ways to realize non-Hermitian topology in the conductance matrix of topological multi-terminal devices. Our work is based on the insight that, in the limit of maximal non-reciprocity, the Hamiltonian for the simplest topological non-Hermitian system “the Hatano-Nelson chain“ effectively describes a one-dimensional, unidirectionally propagating mode. This is analogous to the unidirectional boundary mode of a fully Hermitian topological insulator: the quantum Hall system. We show that the multi-terminal conductance matrix of this system exhibits a topologically protected non-Hermitian skin effect. Our approach can be used to construct and study models that go beyond the Hatano-Nelson model, like the non-Hermitian SSH chain.

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# Niklas Wagner

JMU

## *“Green’s Function Zeros, Spinons and Topology”*

09:10 - 09:30 Wednesday, September 27

In the context of Mott insulators the role of zeros of the Green’s function and their relation to topology have recently attracted considerable interest [1,2,3]. Deep in the Mott phase the zeros show a structure which resembles the non-interacting dispersion. Interestingly, the zeros can also have an inverted, topological structure which, analogously to non-interacting topological insulators, results in zero edge modes. When interfaced with a topological insulator, the edge zeros and edge states annihilate. In this talk I will present results of slave-rotor calculations for the Kane-Mele model which is known to have spinon edge states in the Mott phase [4]. I will demonstrate that these calculations show, consistent with previous methods [1], also the existence of zero edge modes. Zeros and spinons display similar behavior which I will discuss.

[1] N.Wagner et al. Mott insulators with boundary zeros arXiv:2301.05588 (2023)

[2] A. Blason et al. Unified role of Green’s function poles and zeros in topological insulators arXiv:2304.08180v1 (2023)

[3] J.Zhao et al. Failure of Topological Invariants in Strongly Correlated Matter arXiv:2305.02341v1 (2023)

[4] S.Rachel et al. Topological insulators and Mott physics from the Hubbard interaction PRB 82 075106 (2010)

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# Christopher Fuchs

JMU

## *“Limits of the Early Onset Quantum Hall Effect in Paramagnetic (Hg,Mn)Te Quantum Wells”*

09:45 - 10:05 Wednesday, September 27

Paramagnetically doped (Hg,Mn)Te quantum wells ( $\text{Mn} < 4\%$ ) exhibit a non-trivial p-type quantum Hall effect in magnetic fields below 100 mT, the so-called early onset effect (Shamim et al. Sci Adv. 6, eaba4625, 2020). The model presented in the recent work implies that the effect only occurs within a narrow window of layer thickness and Mn doping, which was hit by chance in the discovery of the effect. Here, we present a systematic study of the occurrence of the effect with varying thickness while keeping the Mn concentration constant. The careful investigation of the early onset effect in a first growth batch allows for precise feedback, resulting in a 100 % occurrence rate over the eight samples of a second batch. Thereby, the narrow window to observe the early onset effect is verified experimentally. A device that shows the early onset effect is used to probe the breakdown of the -1 Quantum Hall plateau at large magnetic fields. The plateau extends over two orders of magnitude from  $\sim 100$  mT to more than 10 T. We reveal that the breakdown field is linearly connected to the total carrier density in the sample, just like in HgTe quantum wells that do not show the early onset effect. The latter implies that the non-trivial early onset state smoothly transitions into a standard quantum Hall state with increasing magnetic field.

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# Evgenii Maltsev

IFW Dresden

*“Anomalous Hall Effect in  $\text{EuSn}_2\text{As}_2$  Thin Flakes”*

10:05 - 10:25 Wednesday, September 27

$\text{EuSn}_2\text{As}_2$  is an intrinsic antiferromagnetic topological insulator (TI) with a Néel temperature  $T_N = 24$  K and an easy-plane anisotropy. Despite the interest in magnetic TIs, no transport measurements of  $\text{EuSn}_2\text{As}_2$  nanostructures were reported up until now. Here, we present the first magnetotransport study on exfoliated nanostructures of  $\text{EuSn}_2\text{As}_2$  with thicknesses between 60 nm to 140 nm. In particular, we study the magnetoresistance with respect to magnetic field orientation tilted between out-of-plane and in-plane directions. A small easy-plane magnetic anisotropy is found as previously reported for macrocrystals. Moreover, an anomalous Hall effect (AHE) is observed below  $T_N$ . The complex AHE shape does not appear directly compatible with a simple easy-plane anisotropy pointing to a potentially more complex magnetism in  $\text{EuSn}_2\text{As}_2$  nanostructures.

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# Leonid Bovkun

JMU

## *“Tuning the Band Structure for Narrowgap HgTe QWs with Cd-Doping”*

10:25 - 10:45 Wednesday, September 27

For several decades control of stoichiometric composition for  $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$  is used for narrow gap devices, driving inverted band structure to trivial. For topological 2D systems based on nm-thick HgTe layers similar transition reported with modification of quantum well thickness [1], temperature [2] or strain [3], but not much with the original recipe of Cd-doping.

In the present work we were able to growth series of 9.6 nm samples using molecular beam epitaxy on top of CdTe substrate. The Cd-content in the active layer was aimed at calculated critical value of  $x_c = 4.5\%$  for gapless material. Fig. 2 shows results obtained at 4.2 K for characteristic samples of the batch. For sample with small doping avoided crossing [4] of zero-mode Landau levels is observed as signature of inverted band ordering. For bigger doping no anticrossing is observed and magneto-optical features denoted as  $\alpha$  and  $\beta$  swaps their positions, manifesting reordering of the bands.

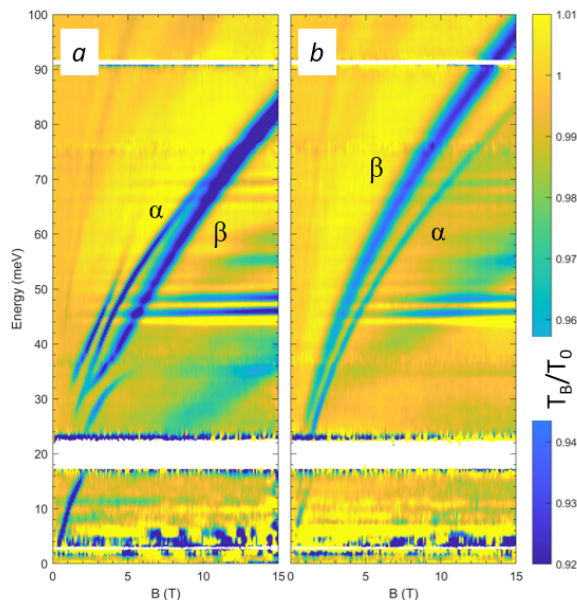


Figure 2: Relative magnetotransmittance  $T_B/T_0$  plotted as false-colour plot in far-infrared range up to 15 Tesla for two samples with different doping: temperatures of Cd-cell a) 155 °C and b) 165 °C.



Observed results can be in further details explained theoretically in the  $k \cdot p$  model but also can be used for adjusting model parameters for further challenging projects based on (Hg,Cd)Te material systems.

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# List of Poster Abstracts

## Quantum Transport Properties of the Superconducting Weyl Semimetal

*Ankit Kumar, IFW Dresden, Germany*



**P1**

Novel quantum materials with band structures showing both topologically non-trivial nature and superconducting properties, in the last decade, a lot of interest due to the interplay between superconductivity and topologically protected electronic surface states and related exciting possibilities of application in the emergent quantum technologies.

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## 2D High Temperature Superconductor Integration in Contact Printed Circuit Boards

P2

*Christian Niclaas Saggau, IFW Dresden, Germany*

Inherent properties of superconducting  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+x}$  films, such as their high superconducting transition temperature  $T_c$ , the efficient Josephson coupling between neighboring CuO layers, and fast quasiparticle relaxation dynamics, make them a promising platform for advances in quantum computing and communication technologies. However, preserving two-dimensional superconductivity throughout the device fabrication is an outstanding experimental challenge due to the fast degradation of its superconducting properties when exposed to moisture, organic solvents, and heating sources. Here, to realize functional superconducting devices based on the sensitive two-dimensional material, we develop a novel fabrication technique relying on the cryogenic dry transfer of printable circuits embedded into a silicon nitride membrane. This approach separates the circuit fabrication stage requiring chemically reactive substances and ionizing physical processes from the creation of the thin superconducting structures. Apart from providing electrical contacts in a single transfer step, the membrane encapsulates the surface of the crystal shielding it from the environment. The fabricated atomically thin  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+x}$  devices show a high superconducting transition temperature  $T_c$  of 91 K equal to that of the bulk crystal and stable superconducting properties.

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# Flat Bands of Surface States in Chiral Symmetric Superconductors

P3

*Clara Johanna Lapp, TU Dresden, Germany*

Noncentrosymmetric superconductors can support flat bands of zero-energy surface states in part of their surface Brillouin zone. This requires that they obey time-reversal symmetry and have a sufficiently strong triplet-to-singlet-pairing ratio to exhibit nodal lines. These bands are protected by a winding number that relies on chiral symmetry, which is realized as the product of time-reversal and particle-hole symmetry. We here reveal a way to stabilize a flat band in the entire surface Brillouin zone, while the bulk dispersion is fully gapped. The necessary ingredient is an additional spin-rotation symmetry that forces the direction of the spin-orbit-coupling vector not to depend on the momentum component normal to the surface, which allows us to block diagonalize the Bogoliubov-de Gennes Hamiltonian. We define a winding number which leads to flat zero-energy surface bands due to bulk-boundary correspondence. In addition, we consider how a weak breaking of the additional symmetry affects the surface band, employing first-order perturbation theory and a quasiclassical approximation. We find that the surface states still persist for a weak breaking of the additional symmetry but that the band does not remain perfectly flat. The broadening of the band strongly depends on the deviation of the spin-orbit-coupling vector from its unperturbed direction as well as on the spin-orbit-coupling strength and the triplet-pairing amplitude.

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## The Superconducting Symmetries of $\text{CeRh}_2\text{As}_2$

*Fabian Jakubczyk, TU Dresden, Germany*

P4

Multiphase unconventional superconductivity is a rare phenomenon, which has recently been discovered in the tetragonal but locally noncentrosymmetric heavy-fermion compound  $\text{CeRh}_2\text{As}_2$ . Here, the transition between two distinct superconducting phases occurs as a function of magnetic field applied along the  $c$  axis ( $H||c$ ) and the formation of superconductivity takes place around  $T_{SCI} \approx 0.3$  K. At  $\mu_0 H^* \approx 4$  T the superconductor changes from a low-field to a high-field state with a large critical field of  $\mu_0 H_{c2} \approx 14$  T. However, for in-plane fields ( $H||ab$ ) only the low-field phase appears, with  $\mu_0 H_{c2} \approx 2$  T. Recent As-NQR & -NMR experiments revealed additional intriguing phenomena in this material, for they detected the onset of antiferromagnetism within the superconducting low-field phase, i.e., at  $T_N < T_{SCI}$ . In order to study the coexistence and interplay of the potential superconducting and magnetic phases, as well as the effect of an external magnetic field, we conduct a symmetry analysis complemented by a Landau free energy expansion. Thereby we can give a statement about the probable symmetries of the superconducting states and their intrinsic connection to magnetism in this material.

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## Observation of Zero Energy States of 1D Gadolinium Chains on Nb(110) Superconducting Surface

P5

*Yu Wang, JMU Würzburg, Germany*

Transition metal adatoms act as magnetic impurities that cause Yu-Shiba-Rusinov (YSR) bound states to form within the energy gap of conventional s-wave superconductors. These bound states are localized at the impurity sites and can assemble into one dimensional (1D) YSR chains that display zero-energy edge states that could be topologically trivial or non-trivial. This study focuses on investigating the impact of rare-earth-metallic species (REMs), specifically Gadolinium atoms as magnetic impurities on Nb(110). The research has revealed the presence of zero-energy states at the edges of chains as short as 5Gd, which may signify the first time that topologically non-trivial zero-energy edge states have been generated from REMs. This discovery could have significant implications for the development of new superconducting materials and the design of future quantum devices.

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# Intermixing-Driven Surface and Bulk Ferromagnetism in the Quantum Anomalous Hall Candidate $\text{MnBi}_6\text{Te}_{10}$

P6

*Abdul-Vakhab Tcakaev, JMU Würzburg, Germany*

The recent realizations of the quantum anomalous Hall effect (QAHE) in  $\text{MnBi}_2\text{Te}_4$  and  $\text{MnBi}_4\text{Te}_7$  benchmark the  $(\text{MnBi}_2\text{Te}_4)(\text{Bi}_2\text{Te}_3)_n$  family as a promising hotbed for further QAHE improvements. The family owes its potential to its ferromagnetically (FM) ordered  $\text{MnBi}_2\text{Te}_4$  septuple layers (SLs). However, the QAHE realization is complicated in  $\text{MnBi}_2\text{Te}_4$  and  $\text{MnBi}_4\text{Te}_7$  due to the substantial antiferromagnetic (AFM) coupling between the SLs. An FM state, advantageous for the QAHE, can be stabilized by interlacing the SLs with an increasing number  $n$  of  $\text{Bi}_2\text{Te}_3$  quintuple layers (QLs). However, the mechanisms driving the FM state and the number of necessary QLs are not understood, and the surface magnetism remains obscure. Here, robust FM properties in  $\text{MnBi}_6\text{Te}_{10}$  ( $n = 2$ ) with  $T_C = 12$  K are demonstrated and their origin is established in the Mn/Bi intermixing phenomenon by a combined experimental and theoretical study. The measurements reveal a magnetically intact surface with a significant magnetic moment and FM properties similar to the bulk. This investigation thus consolidates the  $\text{MnBi}_6\text{Te}_{10}$  system as a perspective for the QAHE at elevated temperatures.

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## Magnetic Warping in Topological Insulators

*Gabriele Naselli, IFW Dresden, Germany*

P7

We analyze the electronic structure of topological surface states in the family of magnetic topological insulators  $\text{MnBi}_{2n}\text{Te}_{3n+1}$ . We show that, at natural-cleavage surfaces, the Dirac cone warping changes its symmetry from hexagonal to trigonal at the magnetic ordering temperature. In particular, an energy splitting develops between the surface states of the same band index but opposite surface momenta upon formation of the long-range magnetic order. As a consequence, measurements of such energy splittings constitute a simple protocol to detect the magnetic ordering via the surface electronic structure, alternative to the detection of the surface magnetic gap. Interestingly, while the latter signals a nonzero surface magnetization, the trigonal warping predicted here is, in addition, sensitive to the direction of the surface magnetic flux. Our results may be particularly useful when the Dirac point is buried in the projection of the bulk states, caused by certain terminations of the crystal or in hole-doped systems, since in both situations the surface magnetic gap itself is not accessible in photoemission experiments.

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# Direct Observation of Mn Anti-Site Sublattice Coupling and its Distinct Ordering Transition in Magnetic Topological Insulator Candidates

P8

*Manaswini Sahoo, IFW Dresden, Germany*

The magnetic topological insulator candidates promise a new era of novel quantum phenomena and their application in spin-based technologies.  $\text{MnBi}_2\text{Te}_4$ , through antiferromagnetic, is the most promising among all, providing tunable magnetic and electronic order by different means. One of them is intermixing where cationic intermixing plays an important role in stabilizing a net magnetization. Here we studied through sensitive local probe techniques like Nuclear magnetic resonance and muon spin relaxation, the role and impact of intermixing on the magnetic properties of all the  $\text{MnBi}_2\text{Te}_4$  ( $\text{Bi}_2\text{Te}_3$ ) $_n$ ,  $n = 0, 1, 2$  family and  $\text{MnSb}_2\text{Te}_4$  powder samples, revealing opposite coupling of the magnetic sites at the ground state and effective decoupling at above certain temperatures. This result opens a new path towards controlling the intermixing as a probe to realize the much anticipated ferromagnetic topological insulators.

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## Bismuth-Rich Intermetallic Rods

*Maria Herz, TU Dresden, Germany*

Black needle-shaped crystals of the bismuth-rich mixed halogenide  $\text{Bi}_{21}\text{Rh}_4\text{Cl}_6\text{I}_7$  showcase an orthorhombic structure that consists of infinite intermetallic rods  ${}_{\text{inf}}^1[\text{Bi}_9\text{Rh}_2]^{3+}$  and discrete anionic groups  $[\text{Bi}_2^{\text{II}}\text{Cl}_2\text{I}_5]^{3-}$  and  $[\text{Bi}^{\text{III}}\text{Cl}_4\text{I}_2]^{3-}$ . The rods consist of Rh-centered  $[\text{RhBi}_8]$  polyhedra that alternately share triangular and rectangular faces. Using traditional electron counting rules, the rod can be interpreted as a covalent polymer with  $\text{Rh}_2$  dumbbells bonded to molecular  $\text{Bi}_2$  and  $\text{Bi}_5$  units, while a quantum-chemical bonding analysis shows that the bonds involving Rh atoms are largely diffuse, while two-center bonds dominate in the bismuth units. Initial resistivity measurements indicate a temperature-independent resistance and this, along with the strong spin-orbit coupling inherent to this bismuth-rich compound, makes it a candidate for a topological insulator.

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## Insights Into the Electronic Properties of Doped Topological Insulators: $\text{Bi}_2\text{Se}_3$ and $\text{Bi}_2\text{Te}_3$

P10

*Shailja Sharma, IFW Dresden, Germany*

Topological insulators (TI) are one of the most exciting and studied systems in condensed matter physics [1]. TI are characterized by the gapless topological surface states that are located inside the bulk band gap [2].  $\text{Bi}_2\text{Se}_3$  and  $\text{Bi}_2\text{Te}_3$  are the typical three-dimensional TI and their surface states have been extensively studied through transport and spectroscopy experiments [3,4]. Here, I will present the detailed electronic transport properties and high-resolution angle-resolved photoemission spectroscopy (ARPES) studies on Ag-doped  $\text{Bi}_2\text{Se}_3$  and Pd-doped  $\text{Bi}_2\text{Te}_3$ . The Dirac cone-like surface states in ARPES confirm that  $\text{Ag}_x\text{Bi}_2\text{Se}_3$  and  $\text{Pd}_x\text{Bi}_2\text{Te}_3$  retain their topological properties even upon doping [5,6].

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# Efficient THz Third Harmonic Generation in Topological HgTe Quantum Wells

*Tatiana Aureliia Uaman Svetikova, HZDR Dresden-Rossendorf, Germany*

**P11**

High harmonic generation (HHG) has applications in various fields, including ultra-short pulse measurements, material characterization, and imaging microscopy. Strong THz nonlinearity and efficient third harmonic generation (THG) have been demonstrated in graphene [1], therefore it is natural to assume the presence of the same effect in other Dirac materials, such as topological insulators (TI) [2,3]. In particular, topological states can be found in HgTe quantum wells with a thickness of more than 6.3 nm [4]. This study presents the third harmonic generation (THG) in an 8 nm-thick HgTe quantum well in the THz spectrum range at different temperatures and THz powers. The fundamental frequency is 0.5 THz, and the efficiency of the THG process approaches 1% in the electric field. Furthermore, we perform a two-color pump-probe experiment with a pump in the range of 20 THz to 28 THz and a broadband THz probe (0.3 THz - 2.5 THz). The free electron laser (FEL) source with intense pulses and a high repetition rate of 13 MHz is used as a pump. Using the intense FEL radiation, we selectively excite Dirac electrons in the surface state of HgTe without affecting the substrate and the buffer layers and probe their relaxation processes. The two-color pump-probe experiment is used to extract the scattering time and conductivity in the framework of the Drude model. We then apply the acceleration model [5] we generalised for arbitrary band dispersion using the experimentally obtained parameters to simulate the observed THG in the HgTe samples. We observe a remarkably good agreement between the experiment and the acceleration model predictions. Our experiments provide insight into the physical mechanisms leading to a giant THz nonlinearity in HgTe-based 2D topological insulators.

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## Triple-Q Order in $\text{Na}_2\text{Co}_2\text{TeO}_6$ from Proximity to Hidden-SU(2)-Symmetric Point

P12

*Wilhelm Krüger, TU Dresden, Germany*

In extended Heisenberg-Kitaev-Gamma-type spin models, hidden-SU(2)-symmetric points are isolated points in parameter space that can be mapped to pure Heisenberg models via nontrivial duality transformations. Such points generically feature quantum degeneracy between conventional single-Q and exotic multi-Q states. We argue that recent single-crystal inelastic neutron scattering data place the honeycomb magnet  $\text{Na}_2\text{Co}_2\text{TeO}_6$  in proximity to such a hidden-SU(2)-symmetric point. The low-temperature order is identified as a triple-Q state arising from the Néel antiferromagnet with staggered magnetization in the out-of-plane direction via a 4-sublattice duality transformation. This state naturally explains various distinctive features of the magnetic excitation spectrum, including its surprisingly high symmetry and the dispersive low-energy and flat high-energy bands. Our result demonstrates the importance of bond-dependent exchange interactions in cobaltates, and illustrates the intriguing magnetic behavior resulting from them.

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## Entropically-Driven Spin-Liquid to Spin-Liquid Thermal Crossover in a Pyrochlore Magnet

*Daniel Lozano-Gómez, TU Dresden, Germany*



**P13**

One of the foremost goals in the study of pyrochlore magnetism is the search for spin-liquid phases composed of highly-disordered yet strongly correlated states. These phases are usually found in Hamiltonians possessing a highly degenerate ground state manifold preventing the onset of long-range order. In this work, we present a spin model on the pyrochlore lattice that realizes a novel classical spin-liquid at intermediate temperatures, collapsing into another spin-liquid phase at low temperatures. We demonstrate that the spin-liquid phase at intermediate temperatures is described by an emerging long-wavelength theory involving both vector and tensor fields, leading to the observation of twofold and fourfold pinch points, as well as, pinch-line singularities in the spin correlation functions. On the other hand, for the low-temperature spin-liquid, an effective long-wavelength theory describing a Coulomb phase is obtained. We demonstrate that the crossover between both phases has an entropic origin, providing the first realization of an entropically-driven selection of a spin-liquid.

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# Research Data Management Services for All of **P14** ct.qmat

*Jonas Schwab, JMU Würzburg, Germany*

We present Research Data Management services provided to all members of ct.qmat. These include the electronic lab notebook eLabFTW, a community edition of Overleaf, a GitLab instance for collaborative source code management and beyond, the Research Data repository NOMAD Oasis and a JupyterHub.

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## Thermal Transport in Weakly Coupled Spin-1/2 Heisenberg Ladders

P15

*Anja Wenger, JMU Würzburg, Germany*

This project aims to comprehend the quantum and thermal properties of the anti-ferromagnetic weakly coupled spin-1/2 Heisenberg ladder exposed to a magnetic field in the low energy limit. By utilizing fermionization and bosonization, we transform the interacting spin ladder into a solvable free boson theory, aligning with the Tomonaga-Luttinger model. We have successfully derived an analytical expression for the Luttinger parameters  $v_F$  (Fermi velocity) and  $K$ , thereby solving the model based on ladder parameters. The introduction of temperature into our theoretical framework allows for a description of thermodynamic quantities. The primary focus of this poster is to investigate the conformal anomaly and how it influences thermal transport. Of note is our observation that thermal transport defies classical theories, implying that, within our model, it is caused by quantum effects exclusively.

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## The VQE Algorithm for the Kagome Heisenberg Model

**P16**

*Richard Strunck, JMU Würzburg, Germany*

The poster gives a short intro to IBM's 16 qubit quantum computer. In its main part, it explains how to prepare a 12 site wave function in such a device. The VQE algorithm is explained in detail. It allows to variationally determine the ground state energy of the system. A discussion of the error correction completes the poster.

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## Metal-Assisted Mechanical Exfoliation of 2D Material Monolayers

P17

*Jiang Qu, IFW Dresden, Germany*

A single MoS<sub>2</sub> monolayer (1L-MoS<sub>2</sub>) with a large size of up to 2 mm was exfoliated and transferred on a silicon substrate with an ultra-flat gold film. Compared with the MoS<sub>2</sub> bulk, the 1L-MoS<sub>2</sub> shows a blue shift for E<sub>2g</sub><sup>1</sup> and a red shift for A<sub>1g</sub> modes in Raman. The photoluminescence (PL) spectroscopy results also confirm the transition from an indirect (MoS<sub>2</sub> bulk) to a direct (1L-MoS<sub>2</sub>) band gap material after exfoliation. A single peak at ~670 nm (~1.86 eV) was observed due to the generation of an A exciton from the direct excitonic transition at the Brillouin zone K-point in the 1L-MoS<sub>2</sub>. Both Raman and PL confirmed the successful exfoliation of the 1L-MoS<sub>2</sub>. Moreover, the Raman and PL of 1L-MoS<sub>2</sub> on the ultra-flat gold film were recorded. Gold-sulfur (Au-S) bond at the interface of 1L-MoS<sub>2</sub> and ultra-flat gold surfaces was observed, confirming the ultra-high yielding of monolayer MoS<sub>2</sub> of gold metal is because of the strong Au–MoS<sub>2</sub> interaction.

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# Unstable Energy Level Alignment at Organic/Transition Metal Dichalcogenide Interfaces

P18

*Hibiki Orio, JMU Würzburg, Germany*

The hybrid interface of organic molecules and transition metal dichalcogenides (TMDCs) is weakly bounded by Van-der-Waals interaction. In this weak-interacted system, the interfacial energy level alignment is not in equilibrium and can be modulated by external perturbations. We investigated the electronic structure of copper phthalocyanine (CuPc) monolayer on different layered materials (graphite, TiSe<sub>2</sub>, and WSe<sub>2</sub>) by means of ultraviolet and x-ray photoelectron spectroscopy. Depending on the substrate, CuPc states show a different characteristic upon three hours of x-ray irradiation. The HOMO level is stable in CuPc/graphite case. However, for TiSe<sub>2</sub> and WSe<sub>2</sub>, we find that the HOMO level shifts by 140 meV and 70 meV, respectively, upon x-ray illumination. Changes in film morphology and beam damages are subtle and insufficient to explain these different time evolution.

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# Light-Matter Interaction of TMDCs in an Open Cavity

P19

*Shiyu Huang, JMU Würzburg, Germany*

With the discovery of graphene, two dimensional materials have attracted wide attention because of their fascinating properties, and transition metal dichalcogenides (TMDCs) have been considered as promising candidates. Excitons in monolayer TMDCs and their heterostructures can strongly couple to electromagnetic fields and are thus ideally suitable for integration in optical microcavities [1,2]. Monolayer of TMDCs shows direct bandgap and tightly-bound exciton with binding energy of few 100s meV [7]. Tungsten-based dichalcogenides presents a very large oscillator strength and high PL emission efficiency, so monolayer WS<sub>2</sub> is a fascinating active medium for forming exciton-polaritons at room temperature and studying hybrid light-matter states [3,4,5,6]. Moiré superlattices is formed by stacking two monolayers of TMDCs with a twist angle or a different lattice constant, which is promising to study optics controlling, excitonic landscapes, and towards exciton topology [8,9,10,11]. Here, we report the light-matter coupling of TMDCs in an open cavity, which is employed to confine the photonic field by two distributed Bragg reflectors (DBR). With the reducing of cavity length, the number of cavity modes reduces, and excitons in the TMDCs interact with the confined optical field. The geometry has the potential to achieve strong light-matter coupling and study polariton physics as well as interaction of excitons and exciton-polaritons [5]. Furthermore, it paves the way to future integration of Moiré heterostructures in tailored high-Q microcavities, with possibilities for electric control, low temperatures, and high magnetic field. Among many exciting properties, exciton Moiré lattices hold the potential for topologically non-trivial excitonic bands at the reconstructed domain boundaries [9].

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# Electronic and Transport Properties of Strained SrNbO<sub>3</sub> Thin Films on SrTiO<sub>3</sub>(001)

P20

*Pampa Sadhukhan, JMU Würzburg, Germany*

The realization of quantum materials (QMs) with both electron correlations and topology is currently under active investigation. In this context, 4d transition metal oxides (TMOs) are excellent candidates, as they offer a good balance between electron-electron correlations and spin-orbit coupling (SOC), and recently good progress has been made in their thin-film synthesis and device fabrication. Recently, a topological band structure was predicted for an orthorhombic phase of SrNbO<sub>3</sub> with  $a^0a^0c^-$  type octahedral rotation [1]. In an experimental study, it has been demonstrated that epitaxial strain can control octahedral rotations in SrNbO<sub>3</sub>/SrTiO<sub>3</sub>(001) (SNO/STO) films breaking the cubic symmetry, which in turn generates a novel Dirac semimetallic phase with extremely high mobility and Berry phase that make it promising for quantum materials applications [2]. In addition, a thickness dependent linear magnetoresistance of up to 150,000% and mobilities as high as 80,000 cm<sup>2</sup>/(V·s) have also recently been reported in SNO/STO heterostructures [3]. The understanding of these observations in the context of unique properties of oxides relies mostly on theoretical descriptions of the SNO electronic structure. Until now, only a few experimental studies exist to explore and understand the electronic properties. Although the synthesis of pristine SNO thin films is challenging due to the metastable nature of the Nb<sup>4+</sup> cation with a  $d^1$  configuration, metastable SNO can be preserved by capping films with an alternative oxide with greater atmospheric stability. In this study, we have grown epitaxial SNO/STO thin films of various thickness using pulsed laser deposition. To protect the surface of the SNO layer from over-oxidation, we passivated the films with an epitaxial STO capping layer. X-ray diffraction has been used to characterize the structure and measure the strain. Transport measurements show a metallic nature of the SNO thin films and high linear magnetoresistance for the strained films in agreement with literature. We have also investigated the role of strain on the electronic properties of the SNO/STO(001) thin films and the buried interfaces by angle dependent x-ray photoemission. Nb 3d core level spectra reveal mixed valence states of Nb<sup>5+</sup>, Nb<sup>4+</sup> and Nb<sup>3+</sup>. We also discuss the systematic change in the Nb 4d states in the region near the Fermi energy with increasing SNO film thickness.

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## Disorder Operator and Rényi Entanglement Entropy of Symmetric Mass Generation

P21

*Zihong Liu, JMU Würzburg, Germany*

In recent years a consensus has gradually been reached that the previously proposed deconfined quantum critical point (DQCP) for spin-1/2 systems, an archetypal example of quantum phase transition beyond the classic Landau paradigm, actually does not correspond to a true unitary conformal field theory (CFT). In this work we carefully investigate another type of quantum phase transition supposedly beyond the similar classic paradigm, the so called asymmetric mass generation (SMG) transition proposed in recent years. We employ the sharp diagnosis including the scaling of disorder operator and Rényi entanglement entropy in large-scale lattice model quantum Monte Carlo simulations. Our results strongly suggest that the SMG transition is indeed an unconventional quantum phase transition and it should correspond to a true  $(2 + 1)d$  unitary CFT.

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## A Toy Model to Investigate the Role of Topology in Quantum Phase Transitions

P22

*Gabriel Rein, JMU Würzburg, Germany*

Topology is believed to play a cardinal role in explaining quantum phase transitions as one can identify topological terms in the action of respective field theories. In this project, we formulate an  $SU(N)$ -invariant version of the Liu-Wang model, a previous model where a QSH mass term is dynamically generated [1], by incorporating electronic flavor degrees of freedom. This generalization not only retains the previously identified semi-metal, quantum spin-Hall insulator and s-wave superconducting phases, but also reveals an emergent valence bond solid phase. Remarkably, for  $N=2$  this rich phase diagram features both a continuous transition corresponding to deconfined quantum criticality and a first-order phase transition driven by interaction strength, both of which can be governed by topological terms. Among these terms is a theta-term, which enables control over their relevance by adjusting the number of electron flavors,  $N$ . This is in analogy to the distinction between integer and half-integer spin chains. By enhancing the symmetry, our approach offers a direct means to investigate the influence of topological effects on quantum phase transitions and to systematically explore their impact.

[1] Y. Liu et al., Nat. Comm. 10, 2658 (2019)

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## Interaction-driven Boundary Effects in Hydrodynamic Flow of Electrons in Finite Sized Graphene Sheets

**P23**

*Adrien Reingruber, JMU Würzburg, Germany*

We present results of QMC simulations of finite sized graphene sheets with zigzag and armchair edges in one direction and periodic boundary conditions in the other direction. We compute the double occupancy, spin-spin and current-current correlations in order to understand the relation between different boundary conditions and the electric flow in hydrodynamic regime. In particular we study the spin ordering and possible appearance of the edge magnetism and its influence on the current flow along the edge and in the bulk.

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## Non-Hermiticity and Parity-Time Symmetry at X-Ray Wavelengths

P24

*Fabian Richter, JMU Würzburg, Germany*

A certain class of Hamiltonians which are non-Hermitian but obey parity-time (PT) symmetry exhibit real spectra thus mimicking Hermitian properties. This theoretical concept has recently found fertile ground in optics and photonics where non-Hermitian eigenstates can be created and superposed through optical gain and loss. So far, these concepts have been mostly discussed in the optical regime. Similar control of x-rays is desirable due to their superior penetration power, high focusability and detection efficiency. Here, we investigate theoretically non-Hermitian x-ray photonics based on PT symmetry in a thin-film cavity setup containing Mössbauer nuclei resonant to the x-ray radiation. These cavities present loss which is modelled by a Lindblad term in the master equation. The presence of an external magnetic field introduces PT-symmetry breaking which could be used to control the properties of x-ray scattering.

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## Superfluid Density of Non-Hermitian Superconductors

*Helene Müller, JMU Würzburg, Germany*



**P25**

A non-Hermitian description usually corresponds to non-equilibrium or open systems. Thus, non-Hermitian superconductors can occur under certain external influence. For example, due to modification of elastic properties of the material via spatiotemporal modulation, pump and/or decay of quasiparticles or light-induced effects. Here, we study whether a non-Hermitian description conserves one of the main properties of a superconducting material: the Meissner effect. This effect occurs in conventional superconductors due to the Cooper condensate, that is characterised by the superfluid density (or stiffness). Thus, we study how the superfluid density changes under different external conditions in a non-Hermitian formalism.

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## Hybrid Higher-Order Skin-Topological Effect in Hyperbolic Lattices

*Changan Li, JMU Würzburg, Germany*



**P26**

We investigate the non-Hermitian Haldane model on hyperbolic 8,3 and 12,3 lattices, and showcase its intriguing topological properties in the simultaneous presence of non-Hermitian effect and hyperbolic geometry. From bulk descriptions of the system, we calculate the real space non-Hermitian Chern numbers by generalizing the method from its Hermitian counterpart and present corresponding phase diagram of the model. For boundaries, we find that skin-topological modes appear in the range of the bulk energy gap under certain boundary conditions, which can be explained by an effective one-dimensional zigzag chain model mapped from hyperbolic lattice boundary. Remarkably, these skin-topological modes are localized at specific corners of the boundary, constituting a hybrid higher-order skin-topological effect on hyperbolic lattices.

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## Multi-Layer Laser-Structured Dielectric Systems for Photonic Transport

P27

*Jakob Lindenthal, TU Dresden, Germany*

Photonic crystals and waveguide arrays are attracting significant research attention in topological phenomena in solid-state physics. Especially for miniaturised photonic arrays in the visible and NIR wavelength range, high refractive index contrasts and precise fabrication are required. Commonly used lithography processes can often satisfy the experimental demands, but prototyping and experimental progress are hindered by long lead times, high processing complexity and high cost. The need for quickly deployable, adaptable, and sufficiently precise structuring processes can be met by femtosecond laser structuring techniques. We present simulation results and experimental approaches characterising the fabrication performance of laser-structured dielectric systems. The results include FDTD simulations of chiral waveguides and topological photonic crystal interfaces at a sub-micrometre feature resolution and experimentally realised systems to underline the feasibility of rapid prototyping in nano-photonics by femtosecond laser structuring. We showcase experimental approaches to use structured multi-layer stacks to induce properties such as chirality in photonic crystals while maintaining a high refractive index contrast allowing the miniaturisation of these systems. The fabrication results are complemented by preliminary optical characterisation results of the fabricated systems, pointing out new pathways for easily accessible, quickly adaptable nano-photonics experimental techniques.

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## Exceptional Points in Strongly Correlated Materials: Spontaneous Symmetry Breaking and Charge Response

P28

*Lorenzo Crippa, JMU Würzburg, Germany*

Strongly correlated electronic materials offer one of the standard platforms to detect and classify non-hermitian topological features. These are generally a consequence of the many-body interaction terms, which entail a non-hermitian self-energy and a nontrivial form for two-particle correlation functions. We show how both effects can stabilize a peculiar type of non-hermitian degeneracies known as Exceptional Points. At the 1-particle level, we assess their presence at the onset of spontaneous symmetry-breaking, for systems whose noninteracting Hamiltonian features an un-protected Dirac dispersion. At the 2-particle level, we observe the emergence of Exceptional Points in the eigenvalue spectrum of generalized local charge susceptibilities in the simple Hubbard model, establishing a link between non-hermitian topology and phase instability of the electronic system.

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## Intensity Asymmetries in Photoemission

*Jakub Schusser, JMU Würzburg, Germany*

Angle-resolved photoemission spectroscopy can provide complex information about the electronic wave functions in the momentum space or real space of crystalline solids. The orbital and spin textures are particularly relevant in providing information about the electronic wave functions in the momentum space of crystalline solids and topological semimetals [1]. Recent studies have discussed how the relative ratio between the strength of spin-orbit coupling in comparison to the energy scale of the inversion-symmetry-breaking potential plays a distinct role in determining the symmetry of linear dichroism (LD) and that both LD and circular dichroism (CD) can thus allow for a better understanding of the photoelectron spin polarization signal and its relation to the spin and orbital nature of the initial states [2,3]. We have extended these studies by introducing intrinsic dichroic observables time-reversal dichroism in angular distribution (TRDAD) [4] and intrinsic linear dichroism in angular distribution (iLDAD) [5] that may provide even more direct access to the electronic initial-state properties. Here we further expand our studies of TRDAD in soft X-ray regime and show its independence on photon energy and geometry as well as discuss how TRDAD can be extracted using circularly polarized light.

- [1] J. Schusser et al., Phys. Rev. Lett. 129, 246404 (2022)
- [2] M. Ünzelmann, et al., Phys. Rev. Lett. 124, 176401 (2020)
- [3] H. Bentmann et al., Phys. Rev. Lett. 119, 106401 (2017)
- [4] S Beaulieu, et al. Physical Review Letters 125, 216404 (2020)
- [5] S Beaulieu, et al. npj quantum materials 6, 93, (2021)

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## Topological Quantum Optics in Atomic Emitter Arrays

**P30**

*Jonathan Sturm, JMU Würzburg, Germany*

Atomic emitter arrays with subwavelength spacing have proven themselves as powerful platforms for the implementation of topological lattice models. Edge states have been shown to allow for robust, emission-free, and directional photon transport due to topological protection. We study the quantum optics of semimetallic lattices and Chern insulators, the latter opening the possibility to realize fractional quantum Hall states in these systems. Furthermore, we investigate whether this approach can be extended to x-ray wavelengths.

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## Acoustic Inclined 2D SSH Model

*Simon Widmann, JMU Würzburg, Germany*



**P31**

We investigate effects of solid state physics using sound waves in periodic systems of coupled resonators. The systems have lattice constants in the centimeter range which leads to eigenstates in the audible frequency range.

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## Fermi Level Tuning of a $\text{MnBi}_2\text{Te}_4$ Monolayer

*Marco Dittmar, JMU Würzburg, Germany*

**P32**

By breaking time reversal symmetry, introducing magnetic order to topological insulators leads to the opening of a 2D surface state gap at the Dirac point. Moreover, tuning the position of the Fermi level inside this gap, enables the observation of exciting new phenomena, such as the quantum anomalous Hall effect (QAHE). Here, we focus on the intrinsic ferromagnetic monolayer of  $\text{MnBi}_2\text{Te}_4$  acting as a magnetic extension of the topological insulator  $\text{Bi}_2\text{Te}_3$  [1,2]. By using molecular beam epitaxy (MBE) we grow a single layer of  $\text{MnBi}_2\text{Te}_4$  on top of the topologically non-trivial p-n-junction of  $\text{Sb}_2\text{Te}_3$  and  $\text{Bi}_2\text{Te}_3$ . Our study contains structural characterization by X-ray diffraction and atomic force microscopy, while the electronic structure is assessed by photoemission spectroscopy. In particular, we show that the position of the Fermi level can be tuned by varying the film thickness of the  $\text{Bi}_2\text{Te}_3$  layer.

[1] M. M. Otrokov et al., 2D Mater 4, 025082 (2017)

[2] P. Kagerer et al., Phys. Rev. Research 5, L022019 (2023)

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# One-Step Model Photoemission Calculations of Type-II Dirac Semimetal PtTe<sub>2</sub> **P33**

*Muthu Prasath Thirugnanasambandam Masilamani, JMU Würzburg, Germany*

Among the transition metal dichalcogenides (TMDC) class, PtTe<sub>2</sub> with trigonal structure belongs to type-II Dirac semimetals and attracted extensive research due to the Dirac points appearing at the band touching points of electron and hole pockets. Here we have studied photoelectrons from the surface and bulk states of PtTe<sub>2</sub> using a state-of-the-art ARPES experiment and one-step photoemission model within the spin-polarized relativistic Korringa-Kohn-Rostoker (SPR-KKR) Green's function method [1,2]. Our model quantitatively reproduces most of the features in the band structure mapped by experimental ARPES. It can differentiate surface and bulk states using the surface barrier potential and determinant criterion within the SPR-KKR package [3]. Previously, it was claimed that the topological surface state (TSS) at  $\sim 1$  eV below the Fermi level in 1T-PdTe<sub>2</sub>, a sister compound of 1T-PtTe<sub>2</sub>, has surface character [4]. Our calculations, however, confirm that this state has bulk character. Moreover, our theoretical model of 1T-PtTe<sub>2</sub> will serve as the basis for future studies of asymmetries in measured spin texture which are induced by the experimental geometry [5] and the spin-orbital texture mapping from the spin- and angle-resolved photoemission.

- [1] H. Ebert et al., Rep. Prog. Phys. 74, 096501 (2011)
- [2] J. Braun et al., Physics Reports 740, 1 (2018)
- [3] J. Schusser et al., Phys. Rev. Lett. 129, 246404 (2022)
- [4] O. J. Clark et al., Phys. Rev. Lett. 120, 156401 (2018)
- [5] T. Heider et al., Phys. Rev. Lett. 130, 146401 (2023).

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## Growth and Spectroscopy of Thin Tellurium Films on Pt(111)

P34

*Nicolai Taufertshöfer, JMU Würzburg, Germany*

Tellurium (Te) deposited on a Pt(111) surface forms a variety of structural phases depending on the Te coverage and post-deposition annealing temperature. The structures range from a Kagome monolayer Te to Van-der-Waals layered bulk transition metal tellurides [1]. Here, we investigate this rich phase diagram using low-energy electron diffraction as well as angle-resolved and x-ray photoelectron spectroscopy (ARPES and XPS). Particular attention is drawn to (i) the energy shifts of the Pt core levels, which indicate rich interface chemistry between the respective film and the metal substrate and (ii) the surface band structure yielding a complex manifolds bands ranging from spin-polarized topological in-gap states to backfoldings of substrate bulk bands induced by the unit cell of the superstructure.

[1] T. Kisslinger, A. Raabgrund, L. Hammer, and M. A. Schneider, FAU Erlangen-Nuernberg (in preparation)

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## Electronic Structure Evolution of Magnetic Weyl Semimetal $\text{Co}_3\text{Sn}_2\text{S}_2$ by Doping and Temperature

P35

*Himanshu Lohani, JMU Würzburg, Germany*

$\text{Co}_3\text{Sn}_2\text{S}_2$  is one of the member of kagome family which has been established as a prototype of magnetic Weyl semimetal with an attractive feature of Weyl points (WPs) proximity to Fermi level. We investigate tuning of the WPs across the Fermi level by different doping within the kagome network (Fe and Ni doping at Co site) and out of the kagome network (In substitution at Sn site). We observe clear shifts of selected bands, which are due both to doping and to the reduction of the magnetic splitting by doping. We discriminate between the two by studying the temperature evolution from ferromagnetic to paramagnetic state. We discuss these shifts with the help of DFT calculations using the Virtual Crystal Approximation.

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## Emergence of Surface States on the Topologically Dark Surface of a Layered Weak 3D Topological Insulator

P36

*Johannes Heßdörfer, JMU Würzburg, Germany*

Weak 3D topological insulators (TI) can be considered as a stack of two-dimensional (2D) TI layers and can be distinguished from strong 3D TIs according to the behavior of their respective surface states [1]. In weak TI, there are topologically non-trivial as well as trivial surfaces (i.e. "dark surfaces") perpendicular and parallel to the layers, respectively. Here, the dark surface of a weak TI  $\text{Bi}_{12}\text{Rh}_3\text{Ag}_6\text{I}_9$  is investigated using scanning tunneling microscopy, angle-resolved and X-ray photoelectron spectroscopy (ARPES and XPS), as well as density functional theory band structure calculations. In particular, the influence of surface preparation on surface termination is highlighted and the emergence of surface states within the 3D bulk band gap is demonstrated.

[1] Fu et al. Phys. Rev. Lett. 98, (2007)

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# STM Growth Studies of 5,14-ol-5,14-diborapentacyclo on Low-Index Coinage Metal Surfaces

*Wun-Chang Pan, JMU Würzburg, Germany*

**P37**

In recent studies [1, 2], heteroatom-doped precursors have frequently been used to polymerize graphene nanoribbons with a large variety of structures or dopant heteroatoms. Using cryogenic scanning tunneling microscopy, we investigated the structure of self-assembled 5,14-ol-5,14-diborapentacyclo (CM218) on Cu(110), Cu(111), and Ag(111). While the order is relatively poor on Cu(110) where only few molecular chains can be observed for the second molecular layer, much better ordered molecular clusters and two-dimensional islands are found on Cu(111) at very low and medium sub-monolayer coverage, respectively. The main focus of our study, though, is on CM218 on Ag(111), where we find that molecular clusters and chains coexist with molecular islands. Topographic images of these honeycomb structures display a pronounced bias dependence. Molecule-functionalized tips allow for high-resolution images of these structures for which we suggest structural models. We investigate the electronic properties by scanning tunneling spectroscopy and differential conductance mapping.

[1] Q. Zhong et al., Nature Chemistry 13, 1133 (2021)

[2] K. Sun et al., Nature Chemistry 15, 136 (2023)

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# The Molecular Nanoprobe Ballistic Transport With Atomic Precision

P38

*Markus Leisegang, JMU Würzburg, Germany*

Low-loss charge carrier transport is of great interest for the realization of efficient and small electronic components. Improvements would minimize heat generation and reduce energy consumption at the same time. However, individual scattering processes that determine the loss in charge carrier transport occur on length scales from nanometers to micrometers. To study these in detail, measurement methods with high temporal or spatial resolution are required. For the latter, few established experiments exist, often based on scanning tunneling microscopy, which are however subject to various limitations. In order to get real space access to charge carrier transport at distances of the mean free path and thus in the ballistic regime, we developed and established the molecular nanoprobe (MONA) technique [1,2]. Hereby, we use a single molecule as a detector for charge carriers, which are injected into the substrate under investigation by the STM tip a few nanometers away from the molecule. The high spatial resolution of MONA combined with the small size of the molecular detector allows atomic control of transport paths down to the single nanometer level. In several publications, we have proven the capabilities of this novel technique, ranging from the influence of artificial [1,2] and natural occurring atomic structures [3] to the propagation of spin-polarized charge carriers in a Rashba-split surface state [5, 6]. Our plan is to extend these measurements to novel QSH materials where transport in low dimension states can shed light on hidden properties of these novel materials.

- [1] J. Kügel et al., *Nano Lett.* 17, 5106 (2017)
- [2] M. Leisegang et al., *Nano Lett.* 18, 2165 (2018)
- [3] M. Leisegang et al., *Phys. Rev. Lett.* 126, 144601 (2021)
- [4] M. Leisegang et al., *J. Phys. Chem. C* 127, 592 (2023)
- [5] P. Härtl et al., *Nat. Comm.*, under consideration (2023)
- [6] P. Härtl et al., arXiv:2303.00393 (2023)

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## Anisotropic Coupling of Individual Vibrational Modes to a Cu(110) Substrate

P39

*Andreas Christ, JMU Würzburg, Germany*

Vibrational modes are an inherent property of molecules where the inter-atomic distances of the atomic constituents oscillate around the equilibrium position. As simple as this motion may appear, it can influence the optical, chemical, and electronic properties of molecules. In some cases, the excitation of specific modes can even induce a structural change of the molecule in form of a tautomerization [1]. This causality is used in the MOlecular NANoprobe (MONA) technique to study a remote excitation of such vibrational modes by ballistic charge carriers with an STM [2]. Here, we present a study on the excitation behavior of porphycene adsorbed on a Cu(110) surface. We measured the anisotropic tautomerization rate for different charge carrier energies in the range between  $-850 \text{ meV} < E < 850 \text{ meV}$ . Our data display a clear inversion at the onset of the N-H stretching mode at  $|E| = 376 \text{ meV}$ . Below this energy, when the N-H bending mode is excited, the excitation probability exhibits maxima perpendicular to the rows of the copper substrate and minima along them. Above this energy the tautomerization process is dominated by the excitation of the N-H stretching mode. Here, the excitation probability is maximal along the rows and constant otherwise. This inversion reflects the orthogonality between the N-H bending and stretching mode. Additionally, we observed an energy-dependent asymmetry in the propagation direction of charge carriers injected into the Cu(110) surface state. This demonstrates the effect of an anisotropic band structure on the tunneling probability into energetically degenerated electronic states.

[1] P. Liljeroth et al., *Science* 317, 1203 (2007)

[2] M. Leisegang et al., *Nano Letters* 18, 2165-2171 (2018)

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# Ballistic Transport of Dirac Fermions in 3D Topological Insulator Quantum Wires

*Titouan Charvin, IFW Dresden, Germany*



P40

Dirac Fermions are describing the Topological Surface States (TSS) of a 3D Topological Insulator (3DTI). When brought to the 1D limit, the TSS are quantized by quantum confinement. The Dirac cone is hence decomposed in 1D subband. The zero-energy mode exhibit a linear, photon-like dispersion, characterized by a dissipationless electronic transport, coined Perfectly Transmitted Mode (PTM) [1]. However, the study of this mode is limited by the intrinsic disorder found in 3DTI systems, leading to an increased number of transport mode. [2] A solution to tackle this limit is to tune the Fermi Level by mixing 3DTI binary crystals with different natures of disorder. [3,4] Our approach consists in studying ternary  $(\text{Bi}_x\text{Sb}_{1-x})_2\text{Te}_3$  and quaternary  $(\text{Bi}_x\text{Sb}_{1-x})_2(\text{Te}_y\text{Se}_{1-y})_3$ , grown with a catalyst-free, vapor transport method. [5] Studying quantum corrections to the transport, we identify the subband contributions to the transport with the aim to detect ballistic features of the PTM

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- [2] Dufouleur, Veyrat, Dassonneville et.al., Sci Rep 7, 45276 (2017)
- [3] Cho, Dellabetta, Zhong et al. Nat Commun 6, 7634 (2015)
- [4] Munning, Breunig, Legg et al., Nat. Commun. 12, 1038 (2021)
- [5] Hansen, Fücke, Charvin et. al., Cryst. Growth Des. 2022, 22, 4, 2354–2363, (2022)

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