TT 6: Topological Semimetals

Time: Monday 9:30–13:00 Location: HSZ 304

TT 6.1 Mon 9:30 HSZ 304

Anomalous Hall and Nernst effects in Kane fermions — •Karun Gadge[1,3], Sumanta Tewari[2], and Girish Sharma[3] — [1]Institute for Theoretical Physics University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen — [2]Department of Physics and Astronomy, Clemson University, Clemson, South Carolina, 29634, USA — [3]School of Basic Sciences, Indian Institute of Technology, Mandi, Mandi 175005, India

Kane fermions are characterized by a linear Dirac cone intersecting with a flat band, resembling a pseudo-spin-1 Dirac semimetal. Similar to relativistic Dirac fermions, Kane fermions satisfy a linear energy-momentum relation and can be classified as being pseudorelativistic. Unlike Dirac fermions, they are not protected by symmetry or by topology, but respect time-reversal symmetry, and can emerge by suitable band engineering, for example, in mercury-telluride compounds. Here we discuss the reminiscences of Berry-phase physics in Kane fermions that emerge in the presence of broken time-reversal symmetry. We discuss anomalous transport in Kane fermions and show its similarity to transport in a Dirac semimetal. Furthermore, we study anisotropy in their response that can be probed in current experiments.
[1] PRB 105, 235420 (2022)

TT 6.2 Mon 9:45 HSZ 304

Automatic generation and topological classification of low-energy Hamiltonians at multi-fold degeneracies — •Kirill Alpin — Max Planck Institute for Solid State Research, Stuttgart, Germany

In this talk, we show a method of generating general high-symmetry Hamiltonian with the goal of topologically classifying all possible multi-fold crossings in bandstructures of condensed matter systems. To do so, we found all higher-dimensional irreducible representations at all high-symmetry points in all space groups. The topological phase diagrams of the automatically generated low-energy Hamiltonian at these k-points were mapped out. During this process, we identified a prevalent topological phase with an unusually high Chern number of 5 in multi-fold point crossings. A material was found featuring this topological phase. Further ab-initio calculations of this materials surface DOS showed a high number of Fermi arcs.

TT 6.3 Mon 10:00 HSZ 304

Finite-size effects in a two-dimensional non-symmorphic wallpaper group lattice — •Miguel Ángel Jiménez Herrera[1] and Dario Bercioux[1,2] — [1]Donostia International Physics Center, 20018 San Sebastian, Spain — [2]IKERBASQUE, Basque Foundation for Science, Euskadi Plaza, 5, 48009 Bilbao, Spain

We investigate the spectral properties of a two-dimensional electronic lattice belonging to the non-symmorphic wallpaper group: the herringbone lattice. Specifically, we focus on the cases of ribbons and flakes geometry. Within a tight-binding description, we study how the different states localize inside the system both for ribbons and flakes. We apply different perturbations and symmetry breaking distortions to the lattice and investigate the robustness of the spectral features. Similarly to the bulk case, where we can gap the band structure or merge the Dirac cones into semi-Dirac cones [1], we recover the same properties along the two main directions that ribbons can be constructed. Finally, we study the finite size effects on this lattice, both on ribbon and flake geometries, and report a spectral flow of states across the bulk-like bands.
[1] Herrera & Bercioux, arXiv:2209.11653.

TT 6.4 Mon 10:15 HSZ 304

Landau quantization in the topological semimetal WTe_2 — •R. Sanchez-Barquilla[1], F. Martin-Vega[1], J. J. Baldovi[2], M. Ochi[3], R. Arita[4], N. H. Jo[5], S. L. Bud'ko[5], P. C. Canfield[5], H. Suderow[1], and I. Guillamon[1] — [1]Laboratorio de Bajas Temperaturas y Altos Campos Magnéticos, UAM, E-28049, Spain — [2]ICMol, UV, 46980 Paterna, Spain. — [3]Department of Physics, Osaka University, Osaka 560-0043, Japan — [4]RIKEN Center, Saitama 351-0198, Japan — [5]Department of Physics and Astronomy, Ames, IA 50011

WTe_2 is a layered semimetal which has sparked much interest due to the non-saturating linear MR and possible non-trivial band structure properties, such as Weyl type-II fermions. Quantum oscillations under magnetic fields signal the passage of Landau levels (LL) through the Fermi level and are easily observed in macroscopic measurements, providing a rather complete view of the FS. However, the Landau quantization of the band structure above and below the Fermi energy has not yet been resolved in detail. We present mK STM measurements up to 14T. We have obtained the band structure close to the Fermi level and identified the main electron and hole pockets thanks to QPI experiments at 0T. When applying magnetic field, the spatially averaged tunneling conductance is devoid of LL and shows no field dependence. Atomically resolved measurements present however Landau quantization. We show that the contribution from the electron and hole pockets to the tunneling density of states (DOS) compensates LL peaks in the spatially averaged DOS. We describe Landau quantization at atomic scale and show a non-trivial energy shift of the LL structure.

TT 6.5 Mon 10:30 HSZ 304

Landau levels in NbAs as seen in magneto-optics: experiment versus modeling — S. Polatkan[1], M. Orlita[2], C. Shekhar[3], C. Felser[3], M. Dressel[1], and •A. V. Pronin[1] — [1]1. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany — [2]LNCMI, CNRS-UGA-UPS-INSA-EMFL, 38042 Grenoble, France — [3]Max-Planck-Institut für Chemische Physik fester Stoffe, 01187 Dresden, Germany

We measured the inter-Landau-level transitions the Weyl semimetal NbAs in magneto-optical experiments and found that the fits with pure Weyl bands do not lead to a satisfactory agreement between theory and experiment. We thus propose a coupled hyperbolic band model, supplemented by detailed 2D band structure cuts, attributing a secondary role to the presence of Weyl points. We argue that this minimalist model is sufficient to describe the measured magneto-optical spectra.

TT 6.6 Mon 10:45 HSZ 304

Static and dynamic magnetic properties of *R*AlSi Weyl semimetals — •Tillmann Weinhold[1], Hank Wu[2,3], Rajib Sarkar[1], George Gill[2], Vadim Grinenko[4], Fazel Tafti[5], Stephen Blundell[2], and Hans-Henning Klauss[1] — [1]TU Dresden, Germany — [2]University of Oxford — [3]MPI for Solid State Research, Stuttgart, Germany — [4]Shanghai JiaoTong University, China — [5]Boston College, MA, USA

Weyl semimetals show interesting electronic transport behavior like anomalous Hall effect and negative magnetoresistance. In the magnetic semimetal NdAlSi spin-density wave order was found below 7.2 K. It is proposed that the magnetic order is driven by RKKY interaction of Weyl fermions on narrow Fermi pockets.

We used NMR and μSR experiments to gain information about local static and dynamic magnetic properties of NdAlSi and discuss the results in comparison with diamagnetic LaAlSi and canted ferromagnetic CeAlSi.

TT 6.7 Mon 11:00 HSZ 304

Optically enhanced terahertz harmonic generation in the Dirac semimetal Cd_3As_2 — •Patrick Pilch[1], Changqing Zhu[1], Renato M. A. Dantas[2], Anneke Reinold[1], Yunkun Yang[3], Faxian Xiu[3], and Zhe Wang[1] — [1]TU Dortmund University, Germany — [2]University of Basel, Switzerland — [3]Fudan University, Shanghai, China

High harmonic generation provides an efficient tool to investigate nonequilibrium dynamics of a driven system, and is also very interesting for applications. Cd_3As_2 is a well-established three-dimensional Dirac semimetal with a topologically protected crossing of linear bands at the Fermi level. Terahertz harmonic generation is observed in Cd_3As_2 due to field-driven intraband kinetics [1]. By optically pumping the electron-doped Cd_3As_2, we observe a strong enhancement of the terahertz third harmonic generation. By investigating the dependence of the terahertz third harmonic generation on the pump fluence and time delay, we can ascribe this enhancement to the kinetics of a long-lived nonequilibrium state which corresponds to a population inversion of electrons and holes in the Dirac cone with a characteristic relaxation time $\tau \leq 10$ ps.
[1] Kovalev, S. et al. Nature Commun. 11, 2451 (2020).

15 min. break

TT 6.8 Mon 11:30 HSZ 304

Signatures of a magnetic-field-induced Lifshitz transition in the ultra-quantum limit of the topological semimetal $ZrTe_5$ — •Stanislaw Galeski[1,2] and Henry Legg[3] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, germany — [2]Physics Institute, Universität Bonn, Bonn, Germany — [3]Department of Physics, University of Basel, Basel, Switzerland

The quantum limit (QL) of an electron liquid, realised at strong magnetic fields, has long been proposed to host a wealth of strongly correlated states of matter. Electronic states in the QL are, for example, quasi-one dimensional (1D), which implies perfectly nested Fermi surfaces prone to instabilities. Whereas the QL typically requires unreachably strong magnetic fields, the topological semimetal $ZrTe_5$ has been shown to reach the QL at fields of only a few Tesla. Here, we characterize the QL of $ZrTe_5$ at fields up to 64 T by a combination of electrical-transport and ultrasound measurements. We find that the Zeeman effect in $ZrTe_5$ enables an efficient tuning of the 1D Landau band structure with magnetic field. This results in a Lifshitz transition to a 1D Weyl regime in which perfect charge neutrality can be achieved. Since no instability-driven phase transitions destabilise the 1D electron liquid for the investigated field strengths and temperatures, our analysis establishes $ZrTe_5$ as a thoroughly understood platform for potentially inducing more exotic interaction-driven phases at lower temperatures.

TT 6.9 Mon 11:45 HSZ 304

The anomalous photo-Nernst effect in a Dirac semimetal — •Maanwinder Partap Singh[1,2], Jonas Kiemle[1,2], Waldemar Schmunk[1,2], Alexander Holleitner[1,2], and Christoph Kastl[1,2] — [1]Walter Schottky Institut, Technical University of Munich, Am Coulombwall 4a, 85748 Garching, Germany. — [2]Munich Center of Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany.

The 3D Dirac semimetal $HfTe_5$ is a model system to study unconventional Hall transport phenomena, such as quasi quantized and anomalous Hall efects, in the limit of very low charge carrier densities. Here, we report on anomalous photocurrents in $HfTe_5$, which are intimately linked to the anomalous Hall and the related Nernst conductivities. As the dominant mechanism of photocurrent generation, we establish a, hitherto hidden, anomalous photo-Nernst effect of 3D Dirac electrons. The anomalous photo-Nernst effect manifests itself as a long-range, photoresponse along the crystal edge arising from a Shockley-Ramo type response and the local symmetry breaking at the edge. The observed temperature and density dependences of the anomalous photo-Nernst currents are consistent with a dominating intrinsic Berry curvature mechanism.

TT 6.10 Mon 12:00 HSZ 304

Field-tunable inverted band gap in GdPtBi: A magneto-optical study — •S. Polatkan[1], E. Uykur[1], A. V. Pronin[1], M. Orlita[2], I. Mohelsky[2], J. Wyzula[2], C. Shekhar[3], C. Felser[3], and M. Dressel[1] — [1]1. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany — [2]LNCMI, CNRS-UGA-UPS-INSA-EMFL, 38042 Grenoble, France — [3]Max-Planck-Institut für Chemische Physik fester Stoffe, 01187 Dresden, Germany

GdPtBi is a half-Heusler compound that was suggested to host triple-point fermions. Such fermions may be transformed into Weyl fermions in magnetic fields. We present magneto-optical data alongside a $\mathbf{k}\cdot\mathbf{p}$ model, evidencing the exchange-interaction mediated pseudo-Zeeman splitting of the parabolic band touching at the Γ point predicted by DFT, and thus prove the existence of highly tunable Weyl cones.

TT 6.11 Mon 12:15 HSZ 304

Anisotropic optics and gravitational lensing of tilted Weyl fermions — •Viktor Könye[1], Lotte Mertens[1,2], Corentin Morice[3], Dmitry Chernyavsky[1], Ali G. Moghaddam[4,5], Jasper van Wezel[2], and Jeroen van den Brink[1,6] — [1]Institute for Theoretical Solid State Physics, IFW Dresden and Wurzburg-Dresden Cluster of Excellence ct.qmat, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Institute for Theoretical Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands — [3]Laboratoire de Physique des Solides, CNRS UMR 8502, Universite Paris-Saclay, F-91405 Orsay Cedex, France — [4]Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan 45137-66731, Iran — [5]Computational Physics Laboratory, Physics Unit, Faculty of Engineering and Natural Sciences, Tampere University, FI-33014 Tampere, Finland — [6]Institute for Theoretical Physics, TU Dresden, 01069 Dresden, Germany

We show that tilted Weyl semimetals with a spatially varying tilt provide a platform for studying analogues to problems in anisotropic optics as well as curved spacetime. Considering particular tilting profiles, we numerically evaluate the time evolution of wave packets. We demonstrate that electron trajectories in such systems can be obtained from Fermat's principle in the presence of an inhomogeneous, anisotropic effective refractive index. On the other hand, we show how the electrons dynamics reveal gravitational features and use them to simulate gravitational lensing around a synthetic black hole.

TT 6.12 Mon 12:30 HSZ 304

Black hole mirages: Electron lensing and Berry curvature effects in inhomogeneously tilted Weyl semimetals — •Andreas Haller[1], Suraj Hedge[2], Chen Xu[2], Christophe De Beule[1,3], Thomas L. Schmidt[1], and Tobias Meng[2] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg — [2]Institute of Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01069 Dresden, Germany — [3]Department of Physics and Astronomy, University of Pennsylvania, Philadelphia PA 19104, USA

In this talk, I present our recent study about electronic transport in Weyl semimetals with spatially varying nodal tilt profiles. We discuss two complementary approaches that characterise the electron flow: solutions of the semiclassical equations of motion, in analogy to those encountered in black hole spacetimes, and large-scale microscopic simulations of a scattering region surrounded by semi-infinite leads. We show that the two approaches lead to equivalent results when the wave packet is sufficiently far from the center of the tilt. The two methods are arguably a powerful toolset in the pursuit of tiltronic devices such as e.g. electronic lenses.

TT 6.13 Mon 12:45 HSZ 304

Weyl-type parallel spin-momentum locking in a chiral topological semimetal — •Niels B. M. Schröter — Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle (Saale), Germany

Orthogonal Rashba-type spin-momentum locking is well-known from semiconductors and topological insulator surface states and has inspired many theoretical proposals for technological applications. In contrast, Weyl-type purely parallel spin-momentum locking – which can be considered the natural counterpart of the Rashba-type – has remained elusive in experiments because all experimentally confirmed Weyl-fermion are described by Pauli matrices that act on an orbital pseudospin rather than the proper electron spin. Recently, chiral topological semimetals (CTS) that host single- and multifold band crossings [1,2] have been predicted to realize parallel spin-momentum locking. Here, we use spin-resolved photoemission to probe the spin-texture Fermi-arc surface states in the CTS PtGa. We find that the electron spin points orthogonal to the Fermi surface contour for momenta close to the projection of a bulk multifold fermion, which is consistent with parallel spin-momentum locking of the latter [3]. We anticipate that our discovery of parallel spin-momentum locking of multifold fermions will lead to the integration of chiral topological semimetals in novel spintronic devices that can be used for field-free switching of magnets with perpendicular magnetic anisotropy, and other novel phenomena.

[1] Schröter et al., Nat. Phys 8 759-65 (2019)
[2] Schröter et al., Science 369, 179-83 (2020)
[3] Krieger et al., arXiv.2210.08221 (2022)