TT 25: Topological Semimetals

Time: Thursday 9:30–13:15 Location: H3

Invited Talk TT 25.1 Thu 9:30 H3

Topology: Open and with diverse backgrounds — •Tobias Meng — Institute of Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01069 Dresden, Germany

The advent of topological physics has been a major disruption in the way we think about condensed matter physics. In its most basic form, topological physics relies on the definition of topological invariants defined from the wave functions in the Brillouin zone, including for example the Chern number governing the Hall effect. Implicitly, this view of topological physics requires closed systems with translation invariance.

In this talk, I will show that the fact that any experimental system is open (coupled to its environment) and never fully translationally invariant can be a resource rather than a nuisance. When suitable couplings to environments and inhomogeneities are induced, topological systems exhibit a plethora of novel phenomena, including black hole analogies and new Hall responses. This highlights that the study of topological systems out of their "comfort zone" (closed and translational invariant) is a worthwhile direction for future research.

TT 25.2 Thu 10:00 H3

Chirality flip of Weyl nodes and its manifestation in strained $MoTe_2$ — •Viktor Könye[1], Adrien Bouhon[2], Ion Cosma Fulga[1], Robert-Jan Slager[3], Jeroen van den Brink[1,4], and Jorge I. Facio[1] — [1]IFW Dresden and Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany — [2]Nordic Institute for Theoretical Physics (NORDITA), Stockholm, Sweden — [3]CM Group, Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom — [4]Institute for Theoretical Physics, TU Dresden, Dresden, Germany

Due to their topological charge, or chirality, the Weyl cones present in topological semimetals are considered robust against arbitrary perturbations. One well-understood exception to this robustness is the pairwise creation or annihilation of Weyl cones, which involves the overlap in energy and momentum of two oppositely charged nodes. Here we show that the topological charge can in fact change sign, in a process that involves the merging of not two, but three Weyl nodes. This is facilitated by the presence of rotation and time-reversal symmetries, which constrain the relative positions of Weyl cones in momentum space. We analyze the chirality flip process, showing that transport properties distinguish it from the conventional, double Weyl merging. Moreover, we predict that the chirality flip occurs in $MoTe_2$, where experimentally accessible strain leads to the merging of three Weyl cones close to the Fermi level. Our work sets the stage to further investigate and observe such chirality flipping processes in different topological materials.

TT 25.3 Thu 10:15 H3

Thermoelectric properties in $TaRhTe_4$, $TaIrTe_4$ and $Mo_xW_{1-x}Te_2$ Weyl semimetals — •Mahdi Behnami[1], Helena Reichlova[1,3], Federico Caglieris[1,2], Matthias Gillig[1], Dmitriy Efremov[1], Grigory Shipunov[1], Saicharan Aswartham[1], Ochkan Kyrylo[1], Joseph Dufouleur[1], and Bernd Büchner[1,3] — [1]IFW Dresden, P.O. Box 270116, 01171 Dresden, Germany — [2]SPIN Consiglio Nazionale delle Ricerche — [3]Technische Universit at Dresden, 01062 Dresden, German

Magneto- and thermo transport are the key properties of metals that not only can be used to study the electronic bands [1] but also have potential applications for heat harvesting. Here we report our results on the thermoelectric properties of Weyl semimetals $TaRhTe_4$, $TaIrTe_4$ and $Mo_xW_{1-x}Te_2$ [2,3,4]. All of these materials show an anomaly in the Nernst and Seebeck effects, while no anomaly can be seen in the standard magnetotransport. We discuss the origin of this anomaly and compare the results obtained with those for two compounds from the same family of materials, WTe_2 and $MoTe_2$.

[1] J. Noky et al., Phys. Rev. B 98, 241106 (2018)
[2] E. Haubold et al. Phys. Rev. B 95, 241108 (2017)
[3] K. Koepernik et al. Phys. Rev. B 93, 201101 (2016)
[4] G. Shipunov et al., J. Phys. Chem. Lett. 12, 28, 67306735 (2021)

TT 25.4 Thu 10:30 H3

***Ab initio* study of nonlinear optical effects on the Weyl semimetal $TaIrTe_4$** — •Álvaro Ruiz Puente[1], Ivo Souza[1,2], Stepan S. Tsirkin[3], and Julen Ibañez-Azpiroz[1,2] — [1]Centro de Física de Materiales, Universidad del País Vasco, 20018 Donostia-San Sebastián, Spain — [2]Ikerbasque Foundation, 48013 Bilbao, Spain — [3]Department of Physics, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

We investigate the bulk photovoltaic effect (BPE), which describes a d.c. nonlinear photocurrent taking place in crystals lacking inversion symmetry. $TaIrTe_4$ is a type II Weyl semimetal displaying such a large d.c. response [1]. In this work we use nonlinear response theory to address the optical properties of the solid and isolate the contribution of the Weyl points to it, calculating the 2nd order shift [2] and 3rd order jerk [3] current contributions. Our analysis relies on a Wannier-interpolation scheme built over *ab initio* calculations. We put our theoretical calculations in context with the experimentally measured data, since these effects are expected to account for the measured photocurrent.

Funding provided by the European Union's Horizon 2020 research and innovation programme under the European Research Council (ERC) grant agreement No 946629.

[1] J. Ma et al., Nat. Mater. 18, 476 (2019)
[2] J. Ibañez-Azpiroz, S. S. Tsirkin, I. Souza, Phys. Rev. B 97, 245143 (2018)
[3] B. M. Fregoso, R. A. Muniz, J. E. Sipe, Phys. Rev. Lett. 121, 176604 (2018)

TT 25.5 Thu 10:45 H3

Control of topological nodal planes in MnSi — •Marc A. Wilde[1,2], Matthias Dodenhöft[1], Arthur Niedermayr[1], Andreas Bauer[1,2], Moritz M. Hirschmann[3], Kirill Alpin[3], Andreas P. Schnyder[3], and Christian Pfleiderer[1,2,4] — [1]Physik Department, Technische Universität München, Garching, Germany — [2]Center for QuantumEngineering (ZQE), Technische Universität München, Garching, Germany — [3]Max Planck Institute for Solid State Research, Stuttgart, Germany — [4]MCQST, Technische Universität München, Garching, Germany

Topologically protected band crossings occurring at points or along lines in reciprocal space have generated widespread interest. In contrast, the existence of entire surfaces on which bands are forced to cross and which can also carry a topological charge has been largely overlooked. This is especially intriguing, since (i) the conditions required for the crossing to occur exactly at the Fermi levels are dramatically relaxed by the two-dimensional nature of the planes and (ii) the reciprocal space separation between partner charges is maximal.

In the field-polarized phase of the chiral magnet MnSi the existence or absence of such topological nodal planes is enforced by the existence of absence of magnetic screw rotation symmetries. By using a combination of symmetry analysis, density functional theory and de Haas-van Alphen quantum oscillation experiments we demonstrate switching of the topological nodal planes by an applied magnetic field [1].

[1] M.A. Wilde et al., Nature 594, 374 (2021)

TT 25.6 Thu 11:00 H3

High-mobility surface conduction in FeSi at low temperatures — •Carolina Burger, Andreas Bauer, Vivek Kumar, Michael Wagner, Ralf Korntner, and Christian Pfleiderer — Physik-Department, Technische Universität München, D-85748 Garching, Germany

We report a study of the correlated small-band-gap semiconductor FeSi, exhibiting a saturation of resistivity below temperatures of a few Kelvin. The magnetic field dependence of the electrical transport properties provides strong evidence of a high-mobility surface conduction channel, that is insensitive to the additional presence of an impurity band in the bulk. The surface conduction channel shares great similarities with properties reported for topological insulators, but displays a striking lack of sensitivity to the presence of ferromagnetic impurities as studied by means of a series of single crystals with slightly different starting compositions. Here, we report measurements of the specific heat and the magnetic torque in order to shed further light on the nature of the high-mobility surface conduction.

[1] Y. Fang, S. Ran, W. Xie, S. Wang, Y. S. Meng, M. B. Maple, Proc. Natl. Acad. Sci. 115, 8558 (2018)

[2] B. Yang, M. Uphoff, Y. Zhang, J. Reichert, A. P. Seitsonen, A. Bauer, C. Pfleiderer, J. V. Barth, Proc. Natl. Acad. Sci. 118, e2021203118 (2021)

15 min. break

TT 25.7 Thu 11:30 H3

Network of topological nodal planes, multifold degeneracies, and Weyl points in CoSi — •Nico Huber[1], Kirill Alpin[2], Andreas P. Schnyder[2], Christian Pfleiderer[1], and Marc A. Wilde[1] — [1]TU Munich — [2]MPI for Solid State Research, Stuttgart

The discovery of multifold-fermions [1,2] and symmetry-enforced topological band crossings that are generically located at the Fermi level [3] has recently generated tremendous interest. However, the putative relationship between all topological charges remained unexplored up to now. We report the experimental identification of symmetry-enforced nodal planes (NPs) in CoSi which together with point degeneracies form a network of topological band crossings. In our study [4] we combined measurements of Shubnikov-de Haas (SdH) oscillations with first-principle electronic structure calculations, a symmetry analysis of SG 198, as well as a direct calculation of the topological charges. The observation of two nearly dispersionless SdH frequency branches is shown to provide clear evidence of four Fermi surface sheets around the R point and their pairwise degeneracy at the NPs on the Brillouin zone boundary. Our results further show that the crystalline symmetry enforces a topological charge of the NPs. Taken together, the comprehensive identification of all topological band crossings in the electronic structure of CoSi we report represents a showcase of an entire network of interconnected topological charges.

[1] Rao et al., Nature 567, 496 (2019)
[2] Sanchez et al., Nature 567, 500 (2019)
[3] Wilde et al., Nature 594, 374 (2021)
[4] Huber et al., arXiv:2107.02820 (accepted in PRL) (2022)

TT 25.8 Thu 11:45 H3

Anomalous evolution of the Nernst effect in trigonal $PtBi_2$ — •Federico Caglieris[1,2,3], Dmitriy Efremov[3], Grigory Shipunov[3], Saicharan Aswartham[3], Arthur Veyrat[3], Joseph Dufouleur[3], Christian Hess[5,3], Bernd Buechner[3,4], and Daniele Marré[1,2] — [1]University of Genova, Via Dodecaneso 33, 16146 Genova (IT) — [2]CNR-SPIN, Corso Perrone 24, 16142 Genova (IT) — [3]Leibniz-Institute for Solid State and Materials Research IFW-Dresden, 01069 Dresden (DE) — [4]Institut fuer Festkoerperphysik, TU Dresden, 01069 Dresden (DE) — [5]Fakultaet fuer Mathematik und Naturwissenschaften, Bergische Universitaet Wuppertal, 42097 Wuppertal (DE)

Trigonal $PtBi_2$ represents an exceptional playground for the exploration of topological materials. In fact, it is a Weyl semimetal with broken inversion symmetry and strong spin-orbit coupling, showing also superconductivity at low temperatures. The Nernst effect has been proven to be a powerful technique to investigate the fermiology of unconventional materials. Moreover, in systems characterized by non-trivial topology, the Nernst coefficient often assumes distinctive features, as observed in various Weyl semimetals. In this work, we deeply investigate the evolution of the Nernst coeffcient in a sigle crystal of trigonal-$PtBi_2$ as a function of different parameters: temperature (T), magnetic field (B) and angle (ŭ3b8) between the magnetic field direction and the c-axis of the sample. In particular, we found an anomalous phenomenology, which could be ascribed to peculiar properties of the Fermi surface.

TT 25.9 Thu 12:00 H3

Fermi surface of the chiral topological semimetal PtGa — •B.V. Schwarze[1,2], M. Uhlarz[1], J. Hornung[1,2], S. Chattopadhyay[1], K. Manna[3,4], S. Shekhar[3], C. Felser[3], and J. Wosnitza[1,2] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence ct.qmat, HZDR, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Max Plank Institute for Chemical Physics of Solids, Germany — [4]Indian Institute of Technology Delhi, India

PtGa is a chiral topological semimetal hosting two band-touching nodes with a maximal Chern number of four. Previously, we reported on angle-resolved photoemission spectroscopy measurements revealing giant spin-split Fermi arcs verifying the topology [1]. Here, we present our detailed investigation of the bulk Fermi surfaces of PtGa with angular-dependent de Haas-van Alphen (dHvA) measurements and band-structure calculations. Strong spin-orbit coupling leads to well separated spin-split bands. Eight bands cross the Fermi energy forming a multitude of Fermi surfaces resulting in intricate dHvA spectra. The assignment of the experimentally observed dHvA frequencies to the corresponding calculated extremal orbits is challenging, because of their considerable quantity and proximity. Yet, the experiment is in good agreement with the calculations further confirming the topological character of PtGa.

[1] M. Yao, K. Manna *et al.*, Nat. Commun. **11**, 2033 (2020).

TT 25.10 Thu 12:15 H3

Raman Spectroscopy with Twisted Light on Chiral Semimetal PdGa — •Florian Büscher[1], Peter Lemmens[1], Chandra Shekhar[2], and Claudia Felser[2] — [1]LENA, TU-BS, Braunschweig, Germany — [2]CPFS, MPI, Dresden, Germany

We use Raman spectroscopy to study phonon intensities as a function of light polarization and magnetic field. The investigated system is the chiral Weyl semimetal PdGa. PdGa has chirally ordered Pd and Ga atoms along the c-axis, forming a helix with a distinct handedness. We observed a unique phonon effect with twisted light on specific modes of PdGa depending on the direction of the magnetic field and the handedness of the incident light.

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TT 25.11 Thu 12:30 H3

Magnetic Kagome metal $ErMn_6Sn_6$ — Yishui Zhou[1], Fabio Orlandi[2], Dmitry Khalyavin[2], Pascal Manuel[2], Thomas Brückel[3], and •Yixi Su[1] — [1]Jülich Centre for Neutron Science JCNS at MLZ, Forschungszentrum Jülich, 85747 Garching, Germany — [2]ISIS Facility, STFC, Rutherford Appleton Laboratory, Didcot OX11 0QX, UK — [3]Jülich Centre for Neutron Science JCNS-2 and Peter Grünberg Institute PGI-4, Forschungszentrum Jülich, 52425 Jülich, Germany

Following the discovery of a quantum-limit magnetic Chern phase in $TbMn_6Sn_6$, the correlated topological metal series RMn_6Sn_6 (R=Gd-Yb, and Y, Lu etc.), that possess an ideal kagome lattice of Mn, have emerged as a new platform to explore the interplay between geometric frustration, non-trivial band topology and magnetism. In particular, for magnetic rare-earth ions contained RMn_6Sn_6, it has been recently found that the topological transport properties, such as the anomalous Hall effect (AHE) and the topological Hall effect (THE), can be engineered intrinsically by rare-earth ions, thus suggesting a close relationship between the localized rare-earth magnetism, itinerant Mn magnetism and non-trivial band-structure topology. We have carried out the single-crystal growth and physical properties characterization of this series of magnetic kagome metals. Our single-crystal neutron diffraction investigation of $ErMn_6Sn_6$ has uncovered a range of magnetic field induced complex magnetic orders that are likely associated to the observed THE in this compound.

TT 25.12 Thu 12:45 H3

Designing 3-dimensional flat bands in nodal-line semimetals — •Alexander Lau[1], Timo Hyart[2], Carmine Autieri[1], Anffany Chen[3], and Dmitry I. Pikulin[4] — [1]Institute of Physics Polish Academy of Sciences, Warsaw, Poland — [2]Aalto University, Espoo, Finland — [3]University of British Columbia, Vancouver, Canada — [4]Microsoft Quantum, Redmond, USA

In materials with flat energy bands, the kinetic energy of the electrons is quenched leading to an enhancement of correlation effects. Research efforts, both theoretically and experimentally, have so far focused on materials and superlattices with two-dimensional energy bands. Two dimensions, however, put severe restrictions on the stability of the low- temperature phases due to enhanced fluctuations. Only three-dimensional flat bands can solve the conundrum of combining exotic flat-band phases with stable order existing at high temperatures. Here, we present a viable way to generate three-dimensional flat bands through strain engineering in topological nodal-line semimetals. We shed light on the underlying mechanism and discuss the competition of the arising superconducting and magnetic orders. The required strain profile can be realized, for instance, by bending the sample, which allows for in situ tuning of the emerging correlated phases and the transition temperatures. We show that these systems support a nontrivial 3D quantum geometry giving rise to large superfluid weight and supercurrents along all directions. Moreover, we identify rhombohedral graphite and CaAgP as promising material candidates to realize our proposal.

TT 25.13 Thu 13:00 H3

Weyl-point teleportation — •György Frank[1,2], Dániel Varjas[3], Gergö Pintér[1,2], and András Pályi[1,2] — [1]Department of Theoretical Physics, Budapest University of Technology and Economics, Hungary — [2]MTA-BME Exotic Quantum Phases Group, Budapest University of Technology and Economics, Hungary — [3]Department of Physics, Stockholm University, AlbaNova University Center, 106 91 Stockholm, Sweden

In this work, we describe the phenomenon of Weyl-point teleportation. Weyl points usually move continuously in the configuration parameter space of a quantum system when the control parameters are varied continuously. However, there are special transition points in the control space where the continuous motion of the Weyl points is disrupted. In such transition points, an extended nodal structure (nodal line or nodal surface) emerges, serving as a wormhole for the Weyl points, allowing their teleportation in the configuration space. A characteristic side effect of the teleportation is that the motional susceptibility of the Weyl point diverges in the vicinity of the transition point, and this divergence is characterized by a universal scaling law. We exemplify these effects via a two-spin model and a Weyl Josephson circuit model. We expect that these effects generalize to many other settings including electronic band structures of topological semimetals.