Low Temperature Physics Division
Fachverband Tiefe Temperaturen (TT)

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Overview of Invited Talks and Sessions

(Lecture halls H6 and H7; Poster P)

Plenary Talks

PV II	Mon	9:00– 9:45	Audimax 2	**Quantum thermodynamics - superconducting circuit approach** — •Jukka Pekola
PV VI	Tue	9:00– 9:45	Audimax 1	**Correlated electrons with knots** — •Silke Bühler-Paschen
PV X	Wed	9:00– 9:45	Audimax 1	**Revealing the topological nature of transport at mesoscopic scales with quantum interferences** — •Helene Bouchiat
PV XI	Wed	9:00– 9:45	Audimax 2	**Quantum choreography to the beat of light** — •Rupert Huber
PV XII	Thu	9:00– 9:45	Audimax 1	**Quantum networks - from dreams to reality** — •Jian-Wei Pan
PV XVII	Fri	9:00– 9:45	Audimax 1	**Superconductivity near room temperature** — •Mikhail Eremets

Invited Talks

TT 2.4	Mon	11:45–12:15	H7	**Electronic instabilities of kagomé metals and density waves in the AV_3Sb_5 materials** — •Leon Balents
TT 4.4	Mon	14:45–15:15	H7	**2D Magnetism and Its Efficient Control** — •Cheng Gong
TT 6.1	Tue	10:00–10:30	H7	**Spin Triplet Superconductivity within Superconductors as Determined by FMR Spin pumping** — •Lesley Cohen
TT 21.1	Thu	13:30–14:00	H7	**A new class of charge density wave superconductors in the topological kagome metals AV_3Sb_5 (A=K, Rb, Cs)** — •Stephen Wilson

Invited talks of the joint symposium SKM Dissertation Prize 2021 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	10:00–10:25	Audimax 2	**Avoided quasiparticle decay from strong quantum interactions** — •Ruben Verresen
SYSD 1.2	Mon	10:25–10:50	Audimax 2	**Co-evaporated Hybrid Metal-Halide Perovskite Thin-Films for Optoelectronic Applications** — •Juliane Borchert
SYSD 1.3	Mon	10:55–11:20	Audimax 2	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYSD 1.4	Mon	11:20–11:45	Audimax 2	**The thermodynamics of stochastic systems with time delay** — •Sarah A.M. Loos
SYSD 1.5	Mon	11:50–12:15	Audimax 2	**First Results on Atomically Resolved Spin-Wave Spectroscopy by TEM** — •Benjamin Zingsem

Invited talks of the joint symposium Potentials for NVs sensing magnetic phases, textures and excitations (SYNV)

See SYNV for the full program of the symposium.

SYNV 1.1	Mon	13:30–14:00	Audimax 2	**Harnessing Nitrogen Vacancy Centers in Diamond for Next-Generation Quantum Science and Technology** — •Chunhui Du
SYNV 1.2	Mon	14:00–14:30	Audimax 2	**Nanoscale imaging of spin textures with single spins in diamond** — •Patrick Maletinsky
SYNV 1.3	Mon	14:30–15:00	Audimax 2	**Spin-based microscopy of 2D magnetic systems** — •Jörg Wrachtrup
SYNV 1.4	Mon	15:15–15:45	Audimax 2	**Exploring antiferromagnetic order at the nanoscale with a single spin microscope** — •Vincent Jacques
SYNV 1.5	Mon	15:45–16:15	Audimax 2	**Nanoscale magnetic resonance spectroscopy with NV-diamond quantum sensors** — •Dominik Bucher

Invited talks of the joint symposium Novel phases and dynamical properties of magnetic skyrmions (SYMS)

See SYMS for the full program of the symposium.

SYMS 1.1	Tue	10:00–10:30	Audimax 2	**Imaging skyrmions in synthetic antiferromagnets by single spin relaxometry** — •Aurore Finco
SYMS 1.2	Tue	10:30–11:00	Audimax 2	**Microwave spectroscopy of the skyrmionic states in a chiral magnetic insulator** — •Aisha Aqeel
SYMS 1.3	Tue	11:15–11:45	Audimax 2	**Archimedean Screw in Driven Chiral Magnets** — •Nina del Ser
SYMS 1.4	Tue	11:45–12:15	Audimax 2	**Frustration-driven magnetic fluctuations as the origin of the low-temperature skyrmion phase in $Co_7Zn_7Mn_6$** — •Jonathan White
SYMS 1.5	Tue	12:15–12:45	Audimax 2	**Magnetic Skyrmions as Topological Multi-Media Influencers** — •Sebastián A. Díaz

Invited talks of the joint symposium Facets of many-body quantum chaos (SYQC)

See SYQC for the full program of the symposium.

SYQC 1.1	Tue	13:30–14:00	Audimax 2	**Holographic interpretation of SYK quantum chaos** — •Alexander Altland
SYQC 1.2	Tue	14:00–14:30	Audimax 2	**Non-Fermi liquids and the lattice** — •Sean Hartnoll
SYQC 1.3	Tue	14:30–15:00	Audimax 2	**Dual-unitary circuits: non-equilibrium dynamics and spectral statistics** — •Bruno Bertini
SYQC 1.4	Tue	15:15–15:45	Audimax 2	**Post-Ehrenfest many-body quantum interferences in ultracold atoms** — •Steven Tomsovic
SYQC 1.5	Tue	15:45–16:15	Audimax 2	**Dynamics in unitary and non-unitary quantum circuits** — •Vedika Khemani

Prize talks of the joint Awards Symposium (SYAW)

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	13:30–14:00	Audimax 1	**Organic semiconductors - materials for today and tomorrow** — •Anna Köhler
SYAW 1.2	Wed	14:00–14:30	Audimax 1	**PbTe/CdTe nanocomposite as an attractive candidate for room-temperature infrared detectors** — •Grzegorz Karczewski
SYAW 1.3	Wed	14:40–15:10	Audimax 1	**Fingerprints of correlation in electronic spectra of materials** — •Lucia Reining
SYAW 1.4	Wed	15:10–15:40	Audimax 1	**Artificial Spin Ice: From Correlations to Computation** — •Naëmi Leo
SYAW 1.5	Wed	15:40–16:10	Audimax 1	**From microwave optomechanics to quantum transport – carbon nanotubes as highly versatile hybrid devices** — •Andreas K. Hüttel
SYAW 1.6	Wed	16:20–16:50	Audimax 1	**Quantum spin dynamics of a spin-1/2 antiferromagnetic Heisenberg-Ising chain** — •Zhe Wang
SYAW 1.7	Wed	16:50–17:20	Audimax 1	**Imaging the effect of electron transfer at the atomic scale** — •Laerte Patera

Invited talks of the joint symposium Spain as Guest of Honor (SYES)

See SYES for the full program of the symposium.

SYES 1.1	Wed	13:30–13:40	Audimax 2	**DFMC-GEFES** — •Julia Herrero-Albillos
SYES 1.2	Wed	13:40–14:10	Audimax 2	**Towards Phononic Circuits based on Optomechanics** — •Clivia M. Sotomayor Torres
SYES 1.3	Wed	14:10–14:40	Audimax 2	**Adding magnetic functionalities to epitaxial graphene** — •Rodolfo Miranda
SYES 1.4	Wed	14:45–15:15	Audimax 2	**Bringing nanophotonics to the atomic scale** — •Javier Aizpurua
SYES 1.5	Wed	15:15–15:45	Audimax 2	**Hydrodynamics of collective cell migration in epithelial tissues** — •Jaume Casademunt
SYES 1.6	Wed	15:45–16:15	Audimax 2	**Understanding the physical variables driving mechanosensing** — •Pere Roca-Cusachs

Invited talks of the joint symposium Attosecond and coherent spins: New frontiers (SYAS)

See SYAS for the full program of the symposium.

SYAS 1.1	Thu	10:00–10:30	Audimax 2	**Ultrafast Coherent Spin-Lattice Interactions in Iron Films** — •Steven Johnson
SYAS 1.2	Thu	10:30–11:00	Audimax 2	**Ultrafast spin, charge and nuclear dynamics: ab-initio description** — •Sangeeta Sharma
SYAS 1.3	Thu	11:15–11:45	Audimax 2	**Light-wave driven Spin Dynamics** — •Martin Schultze
SYAS 1.4	Thu	11:45–12:15	Audimax 2	**All-coherent subcycle switching of spins by THz near fields** — •Christoph Lange
SYAS 1.5	Thu	12:15–12:45	Audimax 2	**Ultrafast optically-induced spin transfer in ferromagnetic alloys** — •Stefan Mathias

Invited talks of the joint symposium Physics of van der Waals 2D heterostructures (SYWH)

See SYWH for the full program of the symposium.

SYWH 1.1	Thu	13:30–14:00	Audimax 2	**Spin interactions in van der Waals topological materials and magnets** — •Saroj Dash
SYWH 1.2	Thu	14:00–14:30	Audimax 2	**Exciton optics, dynamics and transport in atomically thin materials** — •Ermin Malic
SYWH 1.3	Thu	14:30–15:00	Audimax 2	**Correlated Electrons in van der Waals Superlattices: Control and Understanding** — •Tim Wehling
SYWH 1.4	Thu	15:15–15:45	Audimax 2	**Exciton manipulation and transport in 2D semiconductor heterostructures** — •Andras Kis
SYWH 1.5	Thu	15:45–16:15	Audimax 2	**Chern Insulators, van Hove singularities and Topological Flatbands in Magic-angle Twisted Bilayer Graphene*** — •Eva Andrei

Invited talks of the joint symposium The Rise of Photonic Quantum Technologies – Practical and Fundamental Aspects (SYPQ)

See SYPQ for the full program of the symposium.

SYPQ 1.1	Fri	10:00–10:30	Audimax 2	**Quantum dots operating at telecom wavelengths for photonic quantum technology** — •Simone Luca Portalupi
SYPQ 1.2	Fri	10:30–11:00	Audimax 2	**Photonic graph states for quantum communication and quantum computing** — •Stefanie Barz
SYPQ 1.3	Fri	11:00–11:30	Audimax 2	**Rare-earth ion doped solids at sub-Kelvins: practical and fundamental aspects** — •Pavel Bushev
SYPQ 1.4	Fri	11:45–12:15	Audimax 2	**Quantum Light and Strongly Correlated Electronic States in a Moiré Heterostructure** — •Brian Gerardot
SYPQ 1.5	Fri	12:15–12:45	Audimax 2	**Quantum communication in fibers and free-space** — •Rupert Ursin

Sessions

TT 1.1–1.8	Mon	10:00–12:45	H6	**Focus Session: Disordered and Granular Superconductors: Fundamentals and Applications in Quantum Technology I**
TT 2.1–2.5	Mon	10:00–12:45	H7	**Focus Session: Exotic Charge Density Wave States of Matter: Correlations and Topology (joint session TT/HL)**
TT 3.1–3.7	Mon	13:30–16:15	H6	**Focus Session: Entanglement as a Probe for Correlated Quantum Matter**
TT 4.1–4.8	Mon	13:30–16:15	H7	**Focus Session: Correlated van-der-Waals Magnets**
TT 5.1–5.32	Mon	13:30–16:00	P	**Poster Session: Superconductivity**
TT 6.1–6.6	Tue	10:00–12:45	H7	**Focus Session: Emerging Phenomena in Superconducting Low Dimensional Hybrid Systems I**
TT 7.1–7.8	Tue	13:30–16:15	H6	**Focus Session: Disordered and Granular Superconductors: Fundamentals and Applications in Quantum Technology II**
TT 8.1–8.10	Tue	13:30–16:15	H7	**Focus Session: Emerging Phenomena in Superconducting Low Dimensional Hybrid Systems II**
TT 9.1–9.43	Tue	13:30–16:00	P	**Poster Session: Correlated Electrons**
TT 10.1–10.9	Wed	10:00–12:45	H4	**Materials and devices for quantum technology (joint session HL/TT)**
TT 11.1–11.11	Wed	10:00–13:00	H6	**Focus Session: Facets of Many-Body Quantum Chaos (organised by Markus Heyl and Klaus Richter) (joint session DY/TT)**
TT 12.1–12.4	Wed	10:00–11:00	H7	**New Experimental Techniques**
TT 13.1–13.7	Wed	11:15–13:00	H7	**Quantum Computing (joint session TT/DY)**
TT 14.1–14.4	Wed	13:30–14:45	H6	**Many-Body Quantum Dynamics I (joint session DY/TT)**
TT 15.1–15.6	Thu	10:00–11:30	H2	**Many-Body Quantum Dynamics II (joint session DY/TT)**
TT 16.1–16.7	Thu	10:00–12:45	H5	**PhD Focus Session: Symposium on Strange Bedfellows - Magnetism Meets Superconductivity" (joint session MA/AKjDPG) (joint session MA/TT)**
TT 17.1–17.4	Thu	10:00–11:00	H6	**Charge Density Wave Materials**
TT 18.1–18.10	Thu	10:00–12:45	H7	**Frustrated Magnets**
TT 19.1–19.6	Thu	11:15–12:45	H6	**Unconventional Superconductors**
TT 20.1–20.10	Thu	13:30–16:30	H4	**Quantum Dots and Wires (joint session HL/TT)**
TT 21.1–21.7	Thu	13:30–16:00	H7	**Focus Session: Topological Kagome Metals**
TT 22.1–22.9	Thu	13:30–15:30	P	**Poster Session: Disordered and Granular Superconductors: Fundamentals and Applications in Quantum Technology**
TT 23.1–23.3	Thu	13:30–15:30	P	**Poster Session: Emerging Phenomena in Superconducting Low Dimensional Hybrid Systems**
TT 24.1–24.11	Thu	13:30–16:00	P	**Poster Session: Transport**
TT 25.1–25.18	Thu	13:30–16:00	P	**Poster Session: Topology**
TT 26	Thu	18:00–19:30	MVTT	**Annual General Meeting of the Low Temperature Physics Division**
TT 27.1–27.10	Fri	10:00–12:45	H7	**Topological Insulators and Semimetals (joint session TT/KFM)**
TT 28.1–28.6	Fri	13:30–15:00	H6	**Transport (joint session TT/DY)**
TT 29.1–29.6	Fri	13:30–15:00	H7	**Topological Superconductors**

Annual General Meeting of the Low Temperature Physics Division

Thursday 18:00–19:30 MVTT

- Bericht
- Wahl
- Verschiedenes

TT 1: Focus Session: Disordered and Granular Superconductors: Fundamentals and Applications in Quantum Technology I

Superconducting qubits and quantum circuits are traditionally fabricated from simple superconductors such as aluminum or niobium. Recently, strongly disordered and granular superconductors have become a promising alternative for quantum devices that seek a combination of large impedance and low losses: here, the high kinetic inductance of disordered and granular superconductors is a key asset. While these particular materials are in the focus of fundamental superconductivity materials research already for a long time, their application in quantum technologies now motivates a tight interaction of these two research fields.

Organizers: Marc Scheffler (University of Stuttgart), Joachim Ankerhold (Ulm University)

Time: Monday 10:00–12:45 Location: H6

TT 1.1 Mon 10:00 H6

Fate of the superfluid density near the SIT in amorphous superconductors — •Benjamin Sacepe — Néel Institute, CNRS Grenoble, France

Superconducting films of amorphous Indium Oxide (a:InO) thin films undergo a transition to insulation upon increasing disorder, driven by the localization of preformed Cooper pairs. The continuous decrease of the critical temperature as the critical disorder approaches indicates a similarly continuous suppression of the superfluid density. In this talk I discuss the fate of the superfluid density in the vicinity of this transition to insulation. We have accurately measured the superfluid density by a systematic study of the plasmon dispersion spectrum of microwave resonators made of a:InO, combined with DC resistivity measurements, as a function of disorder. We observed that the superfluid stiffness defines the superconducting critical temperature over a wide range of disorder, highlighting the dominant role of phase fluctuations. Furthermore, we found that the superfluid density remains surprisingly finite at the critical disorder, indicating an unexpected first-order nature of the disorder-driven quantum phase transition to insulator.

TT 1.2 Mon 10:30 H6

Superconducting silicon: material and devices — •Francesca Chiodi[1], Pierre Bonnet[1], Daniel Flanigan[2], Raphaelle Delagrange[1], Dominique Débarre[1], and Hélène le Sueur[2] — [1]C2N, Université Paris-Saclay, CNRS, Palaiseau, France — [2]SPEC, Université Paris-Saclay, CEA, CNRS, Gif-sur-Yvette, France

Silicon is one of the most well-known materials, and the main actor in today electronics. Despite this, silicon superconductivity was only discovered in 2006 in laser doped Si:B samples. Laser annealing is instrumental to cross the superconductivity threshold, as the required doping is above the solubility limit, and cannot be reached using conventional micro-electronic techniques. Laser doping allows the realisation of epitaxial, homogeneous, thin silicon layers (5-300 nm) with extreme active doping as high as 11 at. %, and without the formation of B aggregates.

Silicon is a disordered superconductor, with a lower carrier density (1e20 to 5e21 cm-3) than metallic superconductors, a critical temperature modulable with doping from 0 to 0.8 K, and a relatively high resistivity that allows to easily match the devices to the void impedance.

We have realised microwave silicon resonators, working in the 1-12 GHz range and with quality factors about 4000. We have shown a strong non-linear response with power, observing a Kerr coefficient of the order of 300 Hz/photon where less than 1 Hz/photon was expected. To better understand the losses and recombination mechanisms, we have measured the relaxation dynamics of the resonators following a light or a microwave pulse.

TT 1.3 Mon 10:45 H6

Nanocrystalline boron-doped diamond as a model granular superconductor — •Georgina Klemencic[1], David Perkins[2], Jon Fellows[3], Soumen Mandal[1], Chris Muirhead[2], Robert Smith[2], Sean Giblin[1], and Oliver Williams[1] — [1]Cardiff University, UK — [2]University of Birmingham, UK — [3]University of Bristol, UK

We present results of an experimental investigation into Boron-doped Nanocrystalline Diamond (BNCD), which we argue to be an exemplary model for granularity in a low-temperature superconducting system.

Through measurement of the fluctuation conductivity [1], we have indirectly measured the inter- and intragrain diffusion lengths, in an experimental application of the theoretically proposed 'fluctuation spectroscopy' technique. The fluctuation conductivity is well predicted by theories of granular superconductors and the magnetoresistance exhibits the same glassy behaviour as high-T_c samples [2]. In this respect, we find that BNCD is a good system for distinguishing high-T_c behaviours from granular superconductor behaviours.

A special feature of BNCD is its morphology, in which grains extend vertically through the film, making the bulk material structurally akin to a naturally occurring Josephson junction array. In recent work, we have found evidence of metastable phase slip-like excitations in the current-voltage characteristics of macroscopic bridges fabricated from BNCD, which we attribute to this morphology [3].

[1] G. M. Klemencic et al., Phys. Rev. Mater. 1.4 (2017): 044801
[2] G. M. Klemencic et al., Sci. Rep. 9.1 (2019): 1-6
[3] G. M. Klemencic et al., Carbon 175 (2021): 43-49

TT 1.4 Mon 11:00 H6

Distribution of the order parameter in strongly disordered superconductors: analytic theory — •Anton V. Khvalyuk[1,2] and Mikhail V. Feigel'man[2,3] — [1]Skolkovo Institute of Science and Technology, 143026 Skolkovo, Russia — [2]L. D. Landau Institute for Theoretical Physics, 119334 Moscow, Russia — [3]Moscow Institute of Physics and Technology, 117303 Dolgoprudny, Russia

We present an analytic theory of inhomogeneous superconducting pairing in strongly disordered materials, which are moderately close to Superconducting-Insulator Transition. Within our model, single-electron eigenstates are assumed to be Anderson-localized, with a large localization volume. Superconductivity then develops due to coherent delocalization of originally localized preformed Cooper pairs. The key assumption of the theory is that each such pair is coupled to a large number $Z \gg 1$ of similar neighboring pairs. We derived integral equations for the probability distribution $P(\Delta)$ of local superconducting order parameter $\Delta(\boldsymbol{r})$ and analyzed their solutions in the limit of small dimensionless Cooper coupling constant $\lambda \ll 1$. The shape of the order-parameter distribution is found to depend crucially upon the effective number of "nearest neighbors" $Z_{\text{eff}} = 2\nu_0 \Delta Z$. The solution we provide is valid both at large and small Z_{eff}; the latter case is nontrivial as the function $P(\Delta)$ is heavily non-Gaussian. One of our key findings is the discovery of a broad range of parameters where the distribution function $P(\Delta)$ is non-Gaussian but also free of "fat tails" and other features of criticality. The analytic results are supplemented by numerical data, and good agreement between them is observed.

15. min. break

TT 1.5 Mon 11:30 H6

Spectroscopy of a single Josephson impurity in a high kinetic inductance array — •Serge Florens[1], Sébastien Léger[1], Théo Sépulcre[1], Denis Basko[2], Izak Snyman[3], and Nicolas Roch[1] — [1]Néel Institute, CNRS, Grenoble, France — [2]LPMMC, UGA, Grenoble, France — [3]Wits University, Johannesburg, South Africa

Superconducting arrays constitute a promising platform to explore a large class of physical phenomena, from quantum phase transitions to non-linear quantum optics in the microwave domain. We design a fully-tunable model system where a long chain of several thousands linear Josephson elements, acting as a high inductance transmission line, is terminated by a small Josephson junction endowed with a strong non-linearity, acting as a single impurity. From microwave spectroscopic measurements, we extract the phase shift and the inelastic losses induced by the impurity onto the linear modes of the array. In agreement with a microscopic modeling of the circuit, we put into evidence a huge renormalization of the Josephson tunnel energy at the impurity site, and show that the associated enhancement of phase fluctuations provides the dominant dissipation mechanism in the array.

TT 1.6 Mon 12:00 H6

Low energy electrodynamics of strongly disordered superconductors — •Götz Seibold[1], Lara Benfatto[2], and Claudio Castellani[2] — [1]BTU Cottbus-Senftenberg, Cottbus, Germany — [2]University of Rome 'La Sapienza', Rome, Italy

In this contribution we will discuss the static and dynamical response of strongly disordered superconductors based on investigations of the attractive Hubbard model with strong on-site disorder and by including fluctuations beyond the Bogoljubov-de Gennes approach. It turns out that paramagnetic processes mediate the response of all collective modes, with a substantial contribution of charge/phase fluctuations [1,2,3]. In particular, we show that for strongly disordered superconductors phase modes acquire a dipole moment and appear as a subgap spectral feature in the optical conductivity which even survives long-range Coulomb interactions. The same processes turn out to dominate also the third-order current at strong disorder [5]. In this regard we show that disorder strongly influences the polarization dependence of the non-linear response, with a marked difference between the homogenous and the disordered case. Our results are particularly relevant for recent experiments in cuprates, whose band structure is in a first approximation reproduced by our lattice model.

[1] G. Seibold et al., Phys. Rev. B 92, 064512 (2015)
[2] T. Cea et al., Phys. Rev. B 89, 174506 (2014)
[3] G. Seibold et al., Phys. Rev. Lett. 108, 207004 (2012)
[4] G. Seibold et al., Phys. Rev. B 103, 014512 (2021)

TT 1.7 Mon 12:15 H6

Decoupling of the Quasiparticle Number and Lifetime in a Disordered Superconductor Probed by Quasiparticle Fluctuation Measurements — •Steven A. H. de Rooij[1,2], Kevin Kouwenhoven[1,2], Jochem J. A. Baselmans[1,2], Vignesh Murugesan[2], David J. Thoen[1,3], and Pieter J. de Visser[2] — [1]SRON - Netherlands Institute for Space Research, Leiden, The Netherlands — [2]Department of Microelectronics, Delft University of Technology, The Netherlands — [3]Kavli Institute of NanoScience, Delft University of Technology, Delft, The Netherlands

In a superconductor, the number of quasiparticles (N_{qp}) decreases exponentially when lowering the temperature, while the quasiparticle lifetime increases, i.e. $\tau_{qp} \sim 1/N_{qp}$. Measuring quasiparticle fluctuations, induced by thermal fluctuations, give access to both τ_{qp} and N_{qp}. In disordered superconductors, these fundamental quasiparticle properties have hardly been studied, although these materials are widely applied in high kinetic inductance quantum circuits and kinetic inductance detectors. We measured quasiparticle fluctuations in the disordered superconductor β-Ta, embedded in a NbTiN microwave resonator, probing both the dissipation (i.e. quasiparticles) and kinetic inductance (i.e. Cooper-pairs). We observe a non-conventional temperature dependence of τ_{qp}, i.e. $\tau_{qp} \nsim 1/N_{qp}$, which results in a strong reduction of the quasiparticle fluctuations with decreasing temperature. This behavior is similar to that of the conventional superconductor Al, where we relate it to quasiparticle trapping [arXiv:2103.04777], which may also play a role in disordered superconductors.

TT 1.8 Mon 12:30 H6

Current-enhanced superfluid stiffness near the Berezinskii-Kosterlitz-Thouless transition in strongly disordered NbN-films — •Alexander Weitzel[1], Lea Pfaffinger[1], Klaus Kronfeldner[1], Thomas Huber[1], Lorenz Fuchs[1], Sven Linzen[2], Evgenii Il'ichev[2], Nicola Paradiso[1], and Christoph Strunk[1] — [1]Experimental and Applied Physics, Uni Regensburg, Germany — [2]Leibniz Institute of Photonic Technology, Jena, Germany

We investigate resistivity and kinetic inductance in long and ultrathin NbN strips near the superconductor-insulator transition. Resistive transition is dominated by superconducting fluctuations of both amplitude and phase of the order parameter. Near the foot of the transition, the resistivity displays a square-root cusp divergence of the conductance expected for the Berezinski-Kosterlitz-Thouless (BKT) transition. The superfluid stiffness of the very same strip (measured using an RLC-resonator technique) displays a sharp drop close to the universal value of $2T_{\mathrm{BKT}}/\pi$. Current voltage (IV) characteristics become non-linear below T_c, with a complex back-bending shape that signals a heating instability. At lower temperatures, IV-characteristics feature a peculiar negative curvature in a log-log representation. This indicates a reduction of dissipation with respect to the standard power-law behavior of the IV-characteristics and is corroborated by the observation of an unexpected increase of kinetic inductance near the critical current.

TT 2: Focus Session: Exotic Charge Density Wave States of Matter: Correlations and Topology (joint session TT/HL)

The recent observation of charge density waves (CDW) in a variety of topological materials ranging from two-dimensional dichalcogenides, Weyl semimetals and metallic kagome systems has prompted intensive research on the origin and effects of such states. In these systems charge order forms the basis for correlated and topological states of quantum matter: Mott Hubbard correlations, tentative spin-liquid physics and chiral superconductivity in two-dimensional dichalcogenides, the emergence of axionic CDWs in Weyl semimetals and an interplay of Z2 topology, charge order and superconductivity in kagome metals. At the same time topology and electron correlations feed back on the CDW formation and dynamics. In this Focus Session we bring together theorists and experimentalists working in the field to discuss the interplay of charge order, correlations and topology in representative model systems, to identify major open challenges in our understanding of these systems and ultimately reach out for controlling CDW physics in correlated topological states of matter.

Organizers: Roser Valenti (Frankfurt University), Tim Wehling (Bremen University)

Time: Monday 10:00–12:45 Location: H7

TT 2.1 Mon 10:00 H7

Chiral superconductivity in the alternate stacking compound 4Hb-TaS$_2$ — •Amit Kanigel — Technion. Haifa, Israel

We study 4Hb-TaS$_2$, which naturally realizes an alternating stacking of 1T-TaS$_2$ and 1H-TaS$_2$ structures. The former is a well-known Mott insulator, which has recently been proposed to host a gapless spin-liquid ground state. The latter is a superconductor known to also host a competing charge density wave state. We find a superconductor with a T$_c$ of 2.7 Kelvin and anomalous properties, of which the most notable one is a signature of time-reversal symmetry breaking, abruptly appearing at the superconducting transition. This observation is consistent with a chiral superconducting state.

TT 2.2 Mon 10:30 H7

Non-local electronic correlations in 1T-TaS$_2$ out of equilibrium — •Uwe Bovensiepen — University of Duisburg-Essen, Faculty of Physics and Center for Nanointegration (CENIDE), 47048 Duisburg, Germany

Transition metal dichalcogenides with a d^1 transition metal electron configuration exhibit broken symmetry ground states and distorted structures. The formation of charge density wave (CDW) states in conjunction with Mott physics in $1T$-TaS_2 is a well know example. Current efforts aim at microscopic understanding of the intertwined electronic and lattice effects. In this regard experiments in the time domain provide direct insights because the characteristically different timescales of electronic hopping with a time constant $\hbar/J \approx$2 fs and the CDW amplitude period of 400 fs can be well distinguished. In this talk time-resolved photoelectron spectroscopy results will be presented in connection with theoretical results to discuss electronic excitations and their dynamics. Excitation and relaxation of doubly occupied sites is mediated by intersite hopping and coupling to delocalized electrons [1,2]. Comparison with literature indicates that such electron dynamics can be excited selectively, separate from lattice excitations. First experiments towards bulk sensitive, time-resolved photoelectron spectroscopy [3] will be discussed as well.
Funding by the DFG through SFB 1242 is gratefully acknowledged.
[1] Ligges et al., PRL **120**, 166401 (2018)
[2] Avigo et al., PR Research **2**, 022046(R) (2020)
[3] Beyazit et al., PRL **125**, 076803 (2020)

15 min. break

TT 2.3 Mon 11:15 H7

Axionic charge density wave in the Weyl semimetal $(TaSe_4)_2I$ — •Johannes Gooth — Max Planck Institut für Chemische Physik fester Stoffe, Dresden, Germany

An axion insulator is a correlated topological phase, which is predicted to arise from the formation of a charge-density wave in a Weyl semimetal that is, a material in which electrons behave as massless chiral fermions. The accompanying sliding mode in the charge-density-wave phase - the phason - is an axion and is expected to cause anomalous magnetoelectric transport effects. However, this axionic charge-density wave has not yet been experimentally detected. Here, we report the observation of a large positive contribution to the magnetoconductance in the sliding mode of the charge-density-wave Weyl semimetal $(TaSe_4)_2I$ for collinear electric and magnetic fields. The positive contribution to the magnetoconductance originates from the anomalous axionic contribution of the chiral anomaly to the phason current, and is locked to the parallel alignment of the electric and magnetic fields. By rotating the magnetic field, we show that the angular dependence of the magnetoconductance is consistent with the anomalous transport of an axionic charge-density wave. Our results show that it is possible to find experimental evidence for axions in strongly correlated topological condensed matter systems, which have so far been elusive in any other context.

Invited Talk TT 2.4 Mon 11:45 H7

Electronic instabilities of kagomé metals and density waves in the AV_3Sb_5 materials — •Leon Balents — University of California, Santa Barbara

Recently, a new class of kagomé metals, with chemical formula AV_3Sb_5, where A = K, Rb, or Cs, have emerged as an exciting realization of quasi-2D correlated metals with hexagonal symmetry. These materials have been shown to display several electronic orders setting in through thermodynamic phase transitions: multi-component (*3Q*) hexagonal charge density wave (CDW) order below a T_c of 90K, and superconductivity with critical temperature of 2.5K or smaller, and some indications of nematicity and one-dimensional charge order in the normal and superconducting states. Other experiments show a strong anomalous Hall effect, suggesting possible topological physics. I will discuss a theory of these phenomena based in part on strong interactions between electrons at saddle points, as well as ideas related to different competing density wave orders.

TT 2.5 Mon 12:15 H7

Charge density waves and superconductivity in kagome metals — •Titus Neupert — Univertity of Zurich, Zurich, Switzerland

Strongly correlated itinerant electron systems exhibit an intertwining of interactions and electronic band fermiology, including flat bands and van Hove points with diverging density of states, nesting patterns, or band degeneracies –for instance of Dirac type or quadratic band touching. The kagome lattice stands out in that it combines all these characteristics, and has thus been subject to many theoretical investigations. However, material realizations of kagome metals with interaction-induced Fermi instabilities have largely been elusive. The recently discovered family of kagome materials AV3Sb5 has filled this gap, displaying charge ordered and superconducting phases with unconventional properties. In my talk, I will discuss the status quo understanding of these instabilities emanating from a critical synopsis of experiments and theoretical studies.

TT 3: Focus Session: Entanglement as a Probe for Correlated Quantum Matter

The interplay of quantum fluctuations and correlations in many-body systems can result in novel phases with exciting physical phenomena. Celebrated examples are the fractional quantum Hall effect and quantum spin liquids. A generic property of such phases is their non- local entanglement that manifests itself in topological order and fractionalized particle-like excitations. Excitingly, it has been proposed that such topologically ordered phases might be an ideal building block for a fault-tolerant quantum computer. While recent experiments pinpointed the presence of fractionalized excitations in spin-liquid materials, the characteristic underlying property of non-local entanglement remains elusive and evades a direct experimental probe.

Organizers: Alexander Tsirlin (Augsburg University), Frank Pollmann (Technical University Munich)

Time: Monday 13:30–16:15 Location: H6

TT 3.1 Mon 13:30 H6

Measuring quantum entanglement with neutrons — •Alan Tennant — Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

The quantification of entanglement without the need for underlying models and theoretical solutions is an open challenge for measurement in condensed matter. This is particularly important in the case of quantum magnets such as spin liquids where we often lack theories that can connect with measurement. Three quantum entanglement witnesses relevant to neutron scattering have been proposed in the form of one-tangle, two-tangle (concurrence), and quantum Fisher information. We have recently applied these to real quantum magnets and found the one-tangle and quantum Fisher information to be particularly promising. I will show how the entanglement witnesses can be determined using experiment and what can be learned from them about the underlying quantum states.

TT 3.2 Mon 14:00 H6

Observation of E_8 particles in Ising chain quantum magnets — •Zhe Wang — Department of Physics, TU Dortmund University, Dortmund, Germany

Near the transverse-field-induced quantum critical point of the Ising chain, an exotic dynamic spectrum consisting of exactly eight particles was predicted [1], which is uniquely described by an emergent quantum integrable field theory with the E_8 Lie algebra, but rarely explored experimentally. By performing high-resolution terahertz spectroscopy of quantum spin dynamics and comparing to analytical calculation of the dynamical spin correlations, we revealed evidence for the E_8 particles in the Ising chain antiferromagnet $BaCo_2V_2O_8$ [2] as well as in the Ising chain ferromagnet $CoNb_2O_6$ [3] under an applied transverse field. In particular, higher-energy E_8 particles were observed above the low-lying two-particle continua, featuring the quantum many-body effects in the exotic dynamic spectrum [2,3].

[1] A. B. Zamolodchikov, Int. J. Mod. Phys. A 4, 4235 (1989).
[2] Z. Zhang et al., Phys. Rev. B 101, 220411 (2020).
[3] K. Amelin et al., Phys. Rev. B 102, 104431 (2020).

15 min. break

TT 3.3 Mon 14:45 H6

Topologically ordered systems on the digital quantum processor — Kevin Satzinger[3], •Yujie Liu[1,2], Adam Smith[4], Christina Knapp[5,6], Michael Knap[1,2], Kirill Schtengel[7], Pedram Roushan[3], and Frank Pollmann[1,2] — [1]Department of Physics, Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology, M{\"u}nchen, Germany — [3]Google Quantum AI, Mountain View, CA, USA — [4]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, Nottingham, UK — [5]Department of Physics and Institute for Quantum Informationand Matter, California Institute of Technology, Pasadena, CA, USA — [6]Walter Burke Institute for Theoretical Physics, California Institute of Technology, Pasadena, CA, USA — [7]Department of Physics and Astronomy, University of California, Riverside, California, USA

In the first part of the talk, we will discuss the experiment on Sycamore quantum processor where we prepare the ground state of the toric code Hamiltonian using an efficient quantum circuit. We measure a topological entanglement entropy near the expected value of ln 2 and simulate anyon interferometry to extract the braiding statistics of the emergent excitations. We further investigate key aspects of the surface code, including logical state injection and the decay of the non-local order parameter. In the second part of the talk. We generalize our protocol to the more general class of string-net states which host doubled topological order, rendering the braiding of non-abelian anyons possible, as a tool to probe and simulate topological quantum field theory.

TT 3.4 Mon 15:15 H6

Robustness of the thermal Hall effect close to half-quantization in a field-induced spin liquid state — •Jan Bruin[1], Ralf Claus[1], Yosuke Matsumoto[1], Nobuyuki Kurita[2], Hidekazu Tanaka[2], and Hidenori Takagi[1,3] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan — [3]Department of Physics, The University of Tokyo, Bunkyo, Tokyo, Japan

Thermal signatures of fractionalized excitations are a fingerprint of quantum spin liquids (QSLs). In the $J_{eff}=1/2$ honeycomb magnet α-$RuCl_3$, a QSL state emerges upon applying an in-plane magnetic field $H_{||}$ greater than the critical field $H_{C2} \approx 7$ T along the a-axis, where the thermal Hall conductivity (k_{XY}/T) was reported to take on the half-quantized value k_{HQ}/T. This finding was discussed as a signature of an emergent Majorana edge mode predicted for the Kitaev QSL. The $H_{||}$- and T-range of the half-quantized signal and its relevance to a Majorana edge mode are, however, still under debate.

Here we present a comprehensive study of k_{XY}/T in α-$RuCl_3$ with $H_{||}$ up to 13 T and T down to 250 mK, which reveals the presence of an extended region of the phase diagram with $k_{XY}/T \approx k_{HQ}/T$ above H_{C2}. The results are in support of a topological state with a half-quantized k_{XY}/T and suggest an interplay with crossovers or weak phase transitions beyond H_{C2} in α-$RuCl_3$.

TT 3.5 Mon 15:30 H6

Angle-dependent thermodynamic measurements on α-$RuCl_3$ — •Sebastian Bachus[1], David Kaib[2], Anton Jesche[1], Yoshifumi Tokiwa[1], Vladimir Tsurkan[1], Alois Loidl[1], Stephen Winter[2], Alexander Tsirlin[1], Roser Valentí[2], and Philipp Gegenwart[1] — [1]Center for Electronic Correlations and Magnetism, University of Augsburg — [2]Institute of Theoretical Physics, Goethe University Frankfurt

For several years, the field-dependence of the Kitaev material α-$RuCl_3$ has been subject to controversial discussions. Recently, a field-induced Kitaev spin liquid state has been proposed above the critical field for long-range magnetic order. This scenario, however, requires another phase transition towards the partially polarized state upon leaving the spin liquid phase. We utilize a high-resolution alternating field method to precisely determine the magnetic Grüneisen parameter down to 0.5 K in magnetic fields up to 14 T. In combination with specific heat measurements, this allows us to determine the entropy evolution into and out of the presumed topological Kitaev quantum spin liquid regime. We compare our thermodynamic measurements to exact diagonalization results and carefully establish the temperature-field phase diagram. Finally, we discuss implications on the suggested spin liquid phase.

[1] S. Bachus et al., Phys. Rev. B 103, 054440 (2021)
[2] S. Bachus et al., Phys. Rev. Lett. 125, 097203 (2020)

TT 3.6 Mon 15:45 H6

Comparative study of the triangular spin-liquid candidates $NaYbO_2$, $KYbO_2$ and $KYbS_2$ — •Franziska Grussler, Sebastian Bachus, Noah Winterhalter-Stocker, Philipp Gegenwart, and Alexander Tsirlin — Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany

Spin liquid is an entangled state of matter. $NaYbO_2$, $KYbO_2$ and $KYbS_2$ feature the same space group $R\overline{3}m$ as the spin-liquid candidate $YbMgGaO_4$ but evade structural disorder pertinent to that compound. We report a comparative study of the polycrystalline $NaYbO_2$ and $KYbO_2$ and single crystalline $KYbS_2$ including their structural characterization and thermodynamic properties in the milli-K temperature range. The compounds reveal the reduction in magnetic couplings upon replacing Na by K and the enhanced easy-plane anisotropy upon replacing O by S. They show no signs of magnetic order in zero field, but undergo field-induced magnetic order. For $KYbS_2$ a detailed B-T phase diagram is deduced from heat capacity, dilatometry and magnetization measurements for B$\|$c. By studying specific heat of $NaYbO_2$ and $KYbS_2$ at milli-K temperatures, we conclude that between 0.5 T and 2 T, within the putative spin-liquid phase, magnetic specific heat follows quadratic behavior expected for the gapless Dirac spin liquid. Our observations establish gapless nature of the spin-liquid phase of triangular antiferromagnets but show strong similarities to 120-degree ordered triangular antiferromagnets when B$\|$c is applied.

TT 3.7 Mon 16:00 H6

Structural and thermodynamic properties of the spin-liquid candidate $Na_2BaCo(PO_4)_2$ — •Vera P. Bader[1], Alexander A. Tsirlin[1], Ivo Heinmaa[2], Raivo Stern[2], Noah Winterhalter-Stocker[1], and Philipp Gegenwart[1] — [1]Center for Electronic Correlations and Magnetism, University of Augsburg — [2]National Institute of Chemical Physics and Biophysics, Tallinn

The first report of $Na_2BaCo(PO_4)_2$ as a spin liquid candidate [1] brought the compound to the fore. One structural prerequisite is fulfilled as the Co^{2+} ions with an effective spin 1/2 form a frustrated triangular lattice. The low temperature properties found in the literature are rather controversial. On the one hand a clear transition is observed in the heat capacity data in zero magnetic field at 140 mK [2]. One the other hand AC magnetic susceptibility data and ZF-μSR measurements indicate a dynamically fluctuating ground state down to 80 mK [3]. The spin-liquid state is highly sensitive to details of the crystal structure and may be suppressed upon structural disorder. Here, we revise both crystal structure and low-T temperature-field phase diagram of $Na_2BaCo(PO_4)_2$. Using high-resolution synchrotron XRD and NMR, we show symmetry lowering and signatures of structural disorder. Moreover, our milli-K heat capacity, thermal expansion and magnetostriction measurements confirm magnetic order in zero field and reveal field-induced phases expected from a nearest-neighbor triangular antiferromagnet.

[1] Zhong *et al.*, PNAS 116 29 (2019)
[2] Li *et al.*, Nat. Commun 11 4216 (2020)
[3] Lee *et al.*, Phys. Rev B 103 024413 (2021)

TT 4: Focus Session: Correlated van-der-Waals Magnets

Reducing the dimensionality of electronic materials often yields novel phenomena and exceptional physical properties. In layered van-der-Waals (vdW) materials which are formed by structurally stable but out-of-plane only weakly coupled crystalline layers this is, e.g., demonstrated by the presence of long-range magnetic order down to the bilayer in $Cr_2Ge_2Te_6$ and down to the monolayer in CrI_3. For VSe_2, the presence of ferromagnetism even at room temperature has been reported for monolayers while the bulk material is paramagnetic. Due to their quasi-2D, layered vdW-magnets do not only allow to investigate fundamental aspects of electronic correlation in structurally reduced dimensionality, but also hold a promise for technological applications, as demonstrated, e.g., by $Cr_2Ge_2O_6$/NiO heterostructures or $NiPS_3$-based field-effect transistors. Furthermore, the recent discovery of magnetic topological insulators (MTIs) in the $(MnBi_2Te_4)(Bi_2Te_3)$n (n = 0, 1, 2) family of vdW compounds has provided a rich experimental basis for the realization of new emerging physical phenomena such as the quantum anomalous Hall effect, the topological magnetoelectric effect, and majorana fermions emerging in MTIs due to a coexistence of the long-range magnetic order and the topologically nontrivial electronic band structure.

Organizers: Bernd Büchner (IFW Dresden), Rüdiger Klingeler (Heidelberg University)

Time: Monday 13:30–16:15 Location: H7

TT 4.1 Mon 13:30 H7

Topological states in $MnBi_2Te_4$-based magnetic van der Waals materials — •Hendrik Bentmann[1], Raphael. C. Vidal[1], Philipp Kagerer[1], Sebastian Buchberger[1], Celso Fornari[1], Anna Isaeva[2], and Friedrich Reinert[1] — [1]Experimentelle Physik VII and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg — [2]Van der Waals – Zeeman Institute, IoP, University of Amsterdam, 1098 XH Amsterdam, The Netherlands

Magnetic van der Waals materials down to a single monolayer have attracted considerable attention in recent years. In this talk, we will discuss electronic and magnetic properties of $MnBi_2Te_4$-based systems, in which Mn local moments and strong spin-orbit interaction of Bi and Te yield an interplay of magnetism and non-trivial band topology. Using angle-resolved photoemission and X-ray magnetic dichroism, we provide evidence that 3D $MnBi_2Te_4$ realizes an antiferromagnetic topological insulator [1]. Incorporation of non-magnetic Bi_2Te_3 spacer layers in $MnBi_4Te_7$ and $MnBi_6Te_{10}$ yields modified magnetic properties and surface-termination-dependent topological surface states [2]. In the 2D regime, $MnBi_2Te_4$ is a candidate for realizing the quantum anomalous Hall state. We will present ongoing efforts to grow $MnBi_2Te_4$ thin films using molecular beam epitaxy (MBE) [3].

[1] Nature 576, 416 (2019)
[2] Phys. Rev. X 9, 041065 (2019), Phys. Rev. Lett. 126, 176403 (2021)
[3] J. Appl. Phys. 128, 135303 (2020)

TT 4.2 Mon 14:00 H7

Static and dynamic magnetic properties of $(MnBi_2Te_4)(Bi_2Te_3)_n$ ($n = 0, 1$) probed by electron spin resonance technique. — •Alexey Alfonsov[1], Kavita Mehlawat[1,2], Jorge I. Facio[1], Ali G. Moghaddam[1,3], Rajyavardhan Ray[1], Alexander Zeugner[4,5], Manuel Richter[1,5], Anna Isaeva[1,6], Jeroen van den Brink[1,2,5], Bernd Büchner[1,2,5], and Vladislav Kataev[1] — [1]Leibniz IFW Dresden, 01069 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat — [3]IASBS, Zanjan 45137-66731, Iran — [4]H.C. Starck Tungsten GmbH, 38642 Goslar, Germany — [5]TU Dresden, 01062 Dresden, Germany — [6]University of Amsterdam, 1098 XH Amsterdam, The Netherlands

$(MnBi_2Te_4)(Bi_2Te_3)_n$ ($n = 0, 1$) represent a family of van der Waals materials which exhibit a coexistence of topologically nontrivial surface states with intrinsic magnetism. Such unusual combination of properties renders this natural heterostructures very attractive for investigations since it enables a number of exotic phenomena. In this work we address static and dynamic magnetic properties of the title materials in the ordered and disordered states using multifrequency and high field electron spin resonance technique. We show that the spin dynamics of the magnetic building blocks of these compounds, the Mn-based septuple layers (SLs), is inherently ferromagnetic (FM) featuring persisting short-range FM correlations far above the magnetic ordering temperature as soon as the SLs get decoupled either by introducing a nonmagnetic quintuple interlayer, as in $MnBi_4Te_7$, or by applying a moderate magnetic field, as in $MnBi_2Te_4$.

TT 4.3 Mon 14:15 H7

Tuning Magnetic and Transport Properties in Quasi-2D $(Mn_{1-x}Ni_x)_2P_2S_6$ Single Crystals — •S. Aswartham[1], Y. Shemerliuk[1], Y. H. Zhou[2], Z. R. Yang[2], G. Cao[3], A.U.B. Wolter[1], and B. Büchner[1,4] — [1]Institut für Festkörperforschung, Leibniz IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany — [2]Anhui Province Key Laboratory of Condensed Matter Physics at Extreme Conditions, High Magnetic Field Laboratory, Chinese Academy of Sciences, Hefei 230031, China — [3]Department of Physics, University of Colorado at Boulder, Boulder, CO 80309, USA — [4]Institut für Festkörper-und Materialphysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

We report an optimized chemical vapor transport method to grow single crystals of $(Mn_{1-x}Ni_x)_2P_2S_6$ where x = 0, 0.3, 0.5, 0.7, and 1. The structural characterization shows that all crystals crystallize in monoclinic symmetry with the space group $C2/m$ (No. 12). The magnetic measurements of the all as-grown single crystals show long range antiferromagnetic order along all principal crystallographic axes. Overall, the Néel temperature T_N is non-monotonous; with increasing Ni^{2+} doping, the temperature of the antiferromagnetic phase transition first decreases from 80 K for pristine ($Mn_2P_2S_6$ (x = 0) up to x= 0.5 and then increases again to 155 K for pure $Ni_2P_2S_6$ (x = 1). We show that, the magnetic anisotropy switches from out-of-plane to in-plane as a function of composition.

15. min. break

Invited Talk TT 4.4 Mon 14:45 H7

2D Magnetism and Its Efficient Control — •Cheng Gong — University of Maryland, College Park, USA

Magnetism, one of the most fundamental physical properties, has revolutionized significant technologies such as data storage and biomedical imaging, and continues to bring forth new phenomena in emerging materials of reduced dimensionalities. The recently discovered magnetic 2D van der Waals materials provide ideal platforms to enable the atomic-thin, flexible, lightweight magneto-optical and magnetoelectric devices. Though many have hoped that the ultra-thinness of 2D magnets should allow an efficient control of magnetism, the state-of-the-art has not achieved notable breakthroughs to this end. In this talk, I will speak on our experimental discovery of the first 2D ferromagnet, and discuss the strategies of the efficient control of 2D magnetism.

TT 4.5 Mon 15:15 H7

Coulomb-Engineered Magnetism in CrI_3 Monolayer — David Soriano, Alexander Rudenko, Mikhail Katsnelson, and •Malte Rösner — Radboud University, Nijmegen, Netherlands

We present a detailed study on the microscopic origin of magnetism in suspended and dielectrically embedded CrI_3 monolayer. To this end, we down-fold minimal generalized Hubbard models from *ab initio* calculations using the constrained random phase approximation. Within mean-field approximation, we show that these models are capable of describing the formation of localized magnetic moments in CrI_3 and of reproducing electronic properties of full *ab initio* calculations. We find a multi-orbital super-exchange mechanism as the origin of magnetism in CrI_3 resulting from a detailed interplay between effective ferro- and anti-ferromagnetic Cr-Cr d coupling channels, which is decisively affected by the ligand (I) p orbitals. We show how environmental screening such as resulting from encapsulation with hexagonal boron nitride (hBN) of the CrI_3 monolayer affects the Coulomb interaction in the film and how this successively controls its magnetic properties. Driven by a non-monotonic interplay between nearest and next-nearest neighbour exchange interactions we find the magnon dispersion and the Curie temperature to be non-trivially affected by the environmental dielectric screening.

TT 4.6 Mon 15:30 H7

Magnetoelastic coupling in the ferromagnetic van-der-Waals material CrI_3 — •Jan Arneth[1], Martin Jonak[1], Sven Spachmann[1], Mahmoud Abdel-Hafiez[2], Yaroslav Kvashnin[3], and Rüdiger Klingeler[1] — [1]Kirchhoff Institute of Physics, Heidelberg University, Germany — [2]Department of Physics and Astronomy, X-ray Photon Science, Uppsala University, Sweden — [3]Department of Physics and Astronomy, Materials Theory, Uppsala University, Sweden

We present high-resolution thermal expansion and magnetostriction studies on the layered van-der-Waals (vdW) ferromagnet CrI_3 in magnetic fields up to 15 T. Distinct anomalies in the thermal expansion coefficient at the ferromagnetic ordering temperature signal magnetoelastic coupling and allow us to quantify the uniaxial pressure dependencies $\partial T_C/\partial p_i$. While T_C reduces at a rate of -0.4 K/GPa upon the application of in-plane pressure, ferromagnetism is stabilized and the effect is about 4 times larger for out-of-plane pressure. The results are compared with numerical studies. We also observe macroscopic length changes associated with field-induced flipping of antiferromagnetically coupled surface layers in the magnetostriction data. We construct the magnetic phase diagram of bulk CrI_3 and show that magnetostriction is also sensitive to the saturation fields of the FM bulk and AFM surface phases.

TT 4.7 Mon 15:45 H7

Probing magnetic states in 2D layered van-der- Waals materials under pressure — Anirudha Gosh[1], Deobrat Singh[1], Qingge Mu[2], Sergey Medvedev[2], Rajeev Ahuja[1], Olle Eriksson[1], and •Mahmoud Abdel-Hafiez[1] — [1]Uppsala University, Department of Physics and Astronomy, Box 516, SE-751 20 Uppsala, Sweden — [2]Max Planck Institute for Chemical Physics of Solids, D-01187 Dresden, Germany

Two-dimensional van der Waals materials offer a plethora of functional properties that are not only of fundamental interest but are essential for the development of new technological applications. Through combined complementary experimental techniques supplemented with theoretical calculations on high quality CrI3 single crystals, we derive a previously not discussed pressure-temperature phase diagram. TC increases to ~ 66 K with pressure up to ~ 3 GPa and then decreases to ~ 10 K at 21.2 GPa. The origin of this behavior is associated with a decrease in the calculated bond angle from 95^o at ambient pressure to ~ 85^o at 25 GPa. At a pressure above ~ 22 GPa, the magnetically ordered state is highly quenched, possibly driving the system to a Kitaev spin-liquid state at low temperature. Pressure-dependent Raman and resistivity measurements also reveal suppression of the phonon modes and semiconductor to metal transition, respectively above ~ 22 GPa. Furthermore, we will describe our recent experiments on CrCl3 single crystals.

TT 4.8 Mon 16:00 H7

Magnetic- and structural properties of α-$RuCl_3$ under hydrostatic He-gas pressure — •Bernd Wolf[1], Anja Wolter-Giraud[3], Gael Bastien[3], Anna Isaeva[4], David Kaib[2], Aleksandar Razpop[2], Kira Riedl[2], Sananda Biswas[2], Roser Valentí[2], Bernd Büchner[3], and Michael Lang[1] — [1]Physikalisches Institut, GU, SFB/TR 288, D-60438 Frankfurt (M) — [2]Institut für theoretische Physik, GU, SFB/TR 288, D-60438 Frankfurt (M) — [3]Leibniz-Institut für Festkörper- und Werkstoffforschung (IFW) Dresden, 01171 Dresden, Germany — [4]Fakultät für Chemie und Lebensmittelchemie, TUD, 01062 Dresden, Germany

α-$RuCl_3$ is a material to probe fundamental aspects of Kitaev physics despite the occurrence of magnetic order at low temperatures. We followed the idea that the suppression of magnetic order in α-$RuCl_3$ by using external parameters like magnetic field or pressure gives rise to a range where Kitaev physics prevails. We present magnetic susceptibility measurements on α-$RuCl_3$ single crystals under almost ideal hydrostatic pressure conditions. We find that the susceptibility strongly increases with increasing pressure. Furthermore, the magnetic ordering temperature T_N becomes rapidly reduced with pressure but cannot be fully suppressed to $T_N = 0$ due to the occurrence of a pressure-induced dimerization transition. We explain both results microscopically by employing a combination of first principles and finite-temperature Lanczos methods. Importantly, thorough investigations of the experimentally observed magnetic transition at varying pressure and magnetic fields reveal clear indications for a first order transition.

TT 5: Poster Session: Superconductivity

Time: Monday 13:30–16:00 Location: P

TT 5.1 Mon 13:30 P

Proximity effects of superconducting Nb thin films on chiral magnetic substrates — •Julius Grefe[1], Rodrigo de Vasconcellos Lourenço[2], Philip Schröder[1], Jannis Willwater[1], Mauricio de Melo[3], Jochen Litterst[1], Stefan Süllow[1], and Dirk Menzel[1] — [1]Institut für Physik der Kondensierten Materie, TU Braunschweig, Germany — [2]Institut für Angewandte Physik, TU Braunschweig, Germany — [3]Departamento de Física, Universidade Estadual de Maringá, Brazil

Superconducting spin valves consisting only of a single magnetic layer and a thin superconducting film promise simple and compact devices in comparison to established GMR systems. Theory has suggested that the critical temperature T_C of a superconductor can be controlled via the proximity effect with a magnetic system exhibiting a non-collinear spin structure [1]. MnSi being a member of the non-centrosymmetric B20 structure shows helimagnetic spin order below $T_N = 29.5$ K and $B_{C1} = 100$ mT. In the related system $Fe_{1-x}Co_xSi$ the Néel-temperature can be tuned in a range of 0 K - 55 K by variation of the Co concentration. Superconducting Nb thin films have been deposited by molecular beam epitaxy on oriented monocrystalline substrates grown by the Triarc-Czochralski method. The surface quality of the substrates and the Nb films has been investigated by atomic force microscopy resulting in a surface roughness of approximately 2 nm.

[1] N. G. Pugach et al., Appl. Phys. Lett. **111**, 162601 (2017)

TT 5.2 Mon 13:30 P

Substrate enhanced superconductivity in layered materials — •Yann in 't Veld[1], Roelof Groenewald[2], Jan Berges[3], Stephan Haas[2], Mikhail Katsnelson[1], Tim Wehling[3], Ryotaro Arita[4], and Malte Rösner[1] — [1]Radboud University, Nijmegen, The Netherlands — [2]University of Southern Calidornia, Los Angeles, USA — [3]Universität Bremen, Bremen, Germany — [4]University of Tokyo, Tokyo, Japan

External dielectric screening can be used to efficiently tune the Coulomb interaction and plasmonic excitations in layered materials. At the same time, two-dimensional plasmons couple strongly to electrons due to their gapless square-root-like dispersion, which renders them particularly interesting for tunable superconductivity in layered materials. Here, we extend density functional theory for superconductors (SC-DFT) to account for both the full dynamic Coulomb interaction and phonon contributions in two dimensions. We apply this scheme to monolayer MoS_2 and find that external screening indeed strongly enhances the superconducting critical temperature in the low-doping regime.

TT 5.3 Mon 13:30 P

Relativistic first principles theory of Yu–Shiba–Rusinov states: Mn dimers on Nb(110) — •Bendegúz Nyári[1], András Lászlóffy[2], László Szunyogh[1], and Balázs Újfalussy[2] — [1]Budapest University of Technology and Economics, Budapest, Hungary — [2]Wigner RCP, ELKH, Budapest, Hungary

The local magnetic moments of magnetic impurities at superconducting surfaces break the Cooper pairs leading to the formation of localized bound states within the superconducting gap, called as Yu–Shina–Rusinov (YSR) states. In the present work we introduce an *ab initio* theory based on the Green's function embedding technique within the Korringa–Kohn-Rostoker method to solve the Bogoliubov–de Gennes equations for the impurities. We present a detailed study of a Mn adatom and various Mn dimers at the surface of Nb(110), as the building blocks of atomic chains expected to host Majorana zero modes. From the calculated local density of states (LDOS) the spatial distribution of the YSR states is determined and compared with scanning tunneling spectroscopy (STS) measurements. The dimers are calculated in several geometric and magnetic configurations, while also the effect of the spin-orbit coupling (SOC) is investigated. We also study the effect of a relative angle between the atomic spins on the YSR states, where we find that for certain values a zero bias peak can exist in some dimer geometries.

TT 5.4 Mon 13:30 P

Development of an ab initio Bogoliubov-de Gennes method with applications to Nb(110) — •Philipp Rüssmann and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany

Ab initio calculations based on density functional theory (DFT) play a major role in understanding and improving quantum materials. Recently, material platforms for topological superconductivity have attracted a lot of attention. Typically materials require a combination of topological insulator, superconductor and magnetic materials and are promising candidates for the realization of Majorana-based qubits.

In this work we present the Bogoliubov-de Gennes extension of the JuKKR code that is based on the all-electron full-potential relativistic Korringa-Kohn-Rostoker Green-function method (https://jukkr.fz-juelich.de). We demonstrate the features of our code using bulk Nb and Nb(110) surfaces as examples, discussing the importance of spin-orbit coupling and showing calculations of the superconducting gap through the layers of thin films of Nb(110). These calculations establish the computational technology that opens the doors to studying the interfaces of superconductors and topological materials and gain insights into the proximity effect and the interplay of the electronic structure in quantum materials from first-principles calculations.

We acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – Cluster of Excellence Matter and Light for Quantum Computing (ML4Q) EXC 2004/1 – 390534769.

TT 5.5 Mon 13:30 P

Impurities in inhomogeneous superconductors from Density Functional Theory — •David Antognini Silva, Philipp Rüssmann, and Stefan Blügel — Peter Grünberg Institute and Institute for Advanced Simulation, FZ Jülich and JARA, 52425 Jülich, Germany

As impurities in a given material can change the electronic properties of the pristine material and give rise to new unique behaviors, their study is crucial in material science. Very timely examples are impurities, atomic chains or nanostructures in superconductor heterostructures [1] where these defects can be instrumental to in-gap states or *e.g.* identifying Majorana modes in Yu-Shiba-Rusinov chains [2]. The relativistic full-potential Korringa-Kohn-Rostoker Green function (KKR-GF) method, used in the Density Functional Theory (DFT) framework, is particularly suited to perfectly embed impurities in materials. We extend the JuKKR code (https://jukkr.fz-juelich.de) by the Bogoliubov-de Gennes (BdG) formalism to treat inhomogeneous superconductors. In this poster we present an extension of the implementation to the impurity problem and present first results of magnetic impurities on superconductors.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG) under Germany's Excellence Strategy - Cluster of Excellence Matter and Light for Quantum Computing (ML4Q) EXC 2004/1 - 390534769.

[1] Z. Yan, Phys. Rev. B **100**, 205406 (2019)
[2] L. Schneider *et al.*, Nat. Phys. (2021)

TT 5.6 Mon 13:30 P

Relativistic and non-relativistic Ginzburg-Landau models in two-dimensional curved films — •Igor Bogush[1,2] and Vladimir M. Fomin[2,3] — [1]Theoretical Physics, Faculty of Physics, Lomonosov Moscow State University, Leninskie Gory, Moscow, 119991, Russia — [2]Moldova State University, Chisinau MD-2009, Republic of Moldova — [3]Institute for Integrative Nanosciences, Leibniz IFW Dresden, D-01069 Dresden, Germany

Superconductor nanoarchitectures, including self-rolled films, are highly promising for advancements in nano- and meso-scale devices. Superconductivity strongly depends on the external magnetic field applied to thin films. Managing the profile of the magnetic field is a challenging technical problem. To get around this problem, one can give a complex shape to the film such that the normal component of the magnetic field has the desired profile. We solve relativistic and non-relativistic time-dependent Ginzburg-Landau models for two-dimensional curved manifolds by applying the tool of General Relativity, differential geometry. The arbitrary geometry opens the way to manipulate the effective normal component of the magnetic field to control the regions with normal or superconducting state and, as a consequence, to manage the superconducting properties of films, transitions between vortex-chain and phase-slip regimes. We describe numerically nontrivial vortex and phase-slip dynamics and topological transitions in cylindric films and membranes with a deep well.

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TT 5.7 Mon 13:30 P

^{125}Te NMR studies of 1T-$MoTe_2$ under pressure -Towards superconductivity mediated by Weyl Fermions — •Takuto Fujii[1], Hiroshi Yasuoka[1], M.O. Ajeesh[1], Marcus Schmidt[1], Takeshi Mito[2], Michael Nicklas[1], Claudia Felser[1], Andrew Mackenzie[1], and Michael Baenitz[1] — [1]MPI for Chemical Physics of Solids, D-01187 Dresden, Germany — [2]School of Science, University of Hyogo Hyogo, Japan

1T-$MoTe_2$ is claimed to be one of the type-II Weyl semimetals, and has attracted much attention due to its exotic physical properties stemming from the topological (line nodal) band structure where the electron and hole pockets are touching at the E_F. One of the most preeminent features is the occurrence of superconductivity which is stabilized under pressure up to around T_c=7K. In order to understand the superconductivity, we have employed the ^{125}Te NMR technique under pressure (up to 2.17 GPa) and measured the NMR line profile and T_1, determining the Knight shift and low lying magnetic excitations. Using the same NMR tuning circuit, we have also measured the pressure and temperature (T) dependences of the resonant frequency, and extracted the T-dependence of the H_{c2}. The results are not in accord with simple WHH model, but are well fit to an empilical formula, $H_{c2}(T) = H_{c2}(0)[1-\frac{T}{T_c}]^\alpha$. By doing this, we obtained $H_{c2}(0)$=1.50T, T_c= 3.81K, and α=1.1 at 2.17 GPa. A superconducting signature has been observed in $K(T)$ and $1/T_1T(T)$ at around 2.5 K (2.17GPa). We present detailed NMR results and try to explore the superconductivity from the microscopic point of view.

TT 5.8 Mon 13:30 P

Critical current suppression via electrostatic field effect in epitaxial grown nanodevice — •Sohaila Z Noby, Roman Hartmann, Elke Scheer, and Angelo Di Bernardo — Physics department, Universität Konstanz, Germany

Quantum devices based on superconducting materials provide various technological applications, such as e.g. current limiters, electronic filters, routers, digital receivers, and photon detectors. Superconductors demonstrate unconventional pronounced performance under their critical temperatures in industrial electronic circuits in a comparison with semiconductors. However, controlling the electrical conductivity in nanoscale semiconductor devices considers as one of the cornerstones of such technology. This is attributed to the week screening effect, which allows the penetration of the electric field into a lower charge density semiconductor material. Although that phenomenon was believed that can not be realized in superconductor materials due to their higher charge density, which eliminate the field effect on the surface. Recent studies show that the strong electrostatic field can manipulate superconductor characteristics, which their origin still controversial between scientists. This effect has been seen in suppression of the critical current via the application of higher electrostatic field in different material. One such example is niobium (Nb), a well-established suitable elemental superconductor in circuit operation due to its highest critical temperature (~9.2K). In our study the mechanism of field effect, which introduced as a gate voltage, is being studied in a four-terminal nanowire device based on epitaxial grown Nb material.

TT 5.9 Mon 13:30 P

Unconventional Dynamical Scaling close to a Nematic Quantum Critical Point in $FeSe_{0.89}S_{0.11}$ — •Pascal Reiss[1,2], David Graf[3], Amir-Abbas Haghighirad[4], Thomas Vojta[5], and Amalia Coldea[1] — [1]Clarendon Laboratory, University of Oxford, UK — [2]MPI-FKF, Stuttgart, Germany — [3]NHMFL, Tallahassee, USA — [4]IQMT, Karlsruhe Institute of Technology, Germany — [5]Department of Physics, Missouri University of Science and Technology, USA

In the vicinity of quantum critical points, the interplay between electronic and structural order can lead to new and unconventional phases. Of particular interest is the electronic nematic order, with its predicted long-range interactions mediated through the lattices shear modes. Here, we first review the nature of the nematic QCP in $FeSe_{0.89}S_{0.11}$ under hydrostatic pressure. Then, we will demonstrate that the magnetoresistivity close to the QCP obeys a scaling relation over two decades in temperature with diverging critical exponents at low temperatures, in stark contrast to the usual ansatz using fixed exponents. We discuss our findings in the context of disconnected static and dynamic quantum fluctuations, a coupling between electronic and phononic modes, and topological changes of the Fermi surface. These lead to the emergence of an atypical non-zero energy scale at the QCP which strongly affects superconductivity. arXiv:2103.07991

We acknowledge funding from the EPSRC (EP/I004475/1, EP/I017836/1, EP/M020517/1, EP/N01085X/1), the NSF (DMR-1157490, DMR-1828489), the State of Florida, and the John Fell Fund.

TT 5.10 Mon 13:30 P

Growth and characterisation of substitution variants of LaOFeAs single crystals — •Felix Anger[1], Christian Blum[1], Anja Wolter-Giraud[1], Sebastian Gass[1], Hans-Joachim Grafe[1], Saicharan Aswartham[1], Sabine Wurmehl[1,2], and Bernd Büchner[1,2] — [1]Leibniz Institute for Solid State and Materials Research, IFW, Dresden, Germany — [2]Institute of Solid State and Materials Physics, TU Dresden, Dresden, Germany

Facetted LaOFeAs single crystals with considerably growth in the crystallographic c direction were first reported by R. Kappenberger et al. [1]. The growth process takes place via diffusion in solid state, the so-called Solid State Crystal Growth (SSCG) method. The single crystals are grown from a polycrystalline matrix by the introduction of NaAs as a liquid phase to aid the crystallization process.1 Here, we present some additional experimental findings regarding growth temperature, initial microstructure and the role of NaAs for the growth. Furthermore, we are aiming to grow novel series of crystals of substitution variants as, e.g., Co-doped SmOFeAs and LaO1-xFxFeAs. The crystals were characterized regarding their composition, structure and magnetic properties.

[1] R. Kappenberger et al., Journal of Crystal Growth 483, 9-15 (2018)

TT 5.11 Mon 13:30 P

Anomalous softening of phonon-dispersion in the underdoped cuprate superconductors — •Saheli Sarkar[1,2], Maxence Grandadam[1], and Catherine Pépin[1] — [1]Institut de Physique Théorique, Gif-sur Yvette, France — [2]Current affiliation: Institut für QuantenMaterialien und Technologien, Karlsruhe Institute of Technology, Karlsruhe, Germany

Cuprate superconductors possess a complex phase diagram with various other phases like charge density wave (CDW) in the underdoped region. Interestingly, the CDW order has become fundamentally important due to growing evidences of its close relation to the pseudo-gap phase. One leading approach to unravel the relation, is to study the phonon-spectrum which couples to electronic degrees of freedom, thus leaving fingerprints associated with the electronic-structure. Several experiments have observed a softening of the phonon-dispersion in the underdoped cuprates at the CDW ordering wave vector, but only below the superconducting transition temperature. The phonon-softening in cuprates is considered ‘anomalous’ since it is in sharp contrast to the situation in metallic systems where such softening occurs for temperatures below the onset of CDW order. By employing a perturbative approach, we find that a complex interplay among the CDW order, superconductivity and a finite quasi-particle lifetime arising from an unusually connected thermal fluctuations of these orders, can explain the ‘anomalous’ nature of the phonon-softening, also giving good accounts for other features observed in recent inelastic-Xray scattering experiments.

TT 5.12 Mon 13:30 P

Enhanced Higgs oscillations in unconventional superconductors — •Matteo Puviani[1], Dirk Manske[1], and Rudi Hackl[2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Walther Meissner Institut, Bayerische Akademie der Wissenschaften, Garching, Germany

In superconductors the Anderson-Higgs mechanism allows for the existence of a collective amplitude (Higgs) mode which can couple to eV-light mainly in a non-linear Raman-like process. While the observed properties of the Higgs mode in clean, conventional, isotropic superconductors can be explained within a BCS picture, strong interaction effects with other modes in anisotropic d-wave superconductors are likely. In our work we have calculated the Raman contribution of the Higgs mode from a new perspective, including many-body Higgs oscillations effects and their consequences in steady-state Raman spectroscopy [1]. This solves the long-standing problem of the A1g symmetry Raman spectrum in d-wave superconductors [2]. In order to test our theory, we predicted the presence of measurable characteristic oscillations in THz quench-optical probe time-dependent reflectivity experiments[1,3].

[1] M. Puviani et al., arxiv: 2012.01922
[2] T.P. Devereaux et al., Phys. Rev. Lett. 72, 396 (1994)
[3] S. Nakamura et al., Phys. Rev. Lett. 122, 257001 (2019)

TT 5.13 Mon 13:30 P

Higgs mode mediated enhancement of interlayer transport in high-T_c cuprate superconductors — •Guido Homann[1], Jayson G. Cosme[1,2,3], Junichi Okamoto[4,5], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [3]National Institute of Physics, University of the Philippines, Diliman, Philippines — [4]Institute of Physics, University of Freiburg, Freiburg, Germany — [5]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Freiburg, Germany

We put forth a mechanism for enhancing the interlayer transport in cuprate superconductors, by optically driving plasmonic excitations along the c axis with a frequency that is blue-detuned from the Higgs frequency [1]. The plasmonic excitations induce a collective oscillation of the Higgs field which induces a parametric enhancement of the superconducting response, as we demonstrate with a minimal analytical model. Furthermore, we perform simulations of a particle-hole symmetric $U(1)$ lattice gauge theory and find good agreement with our analytical prediction. Our numerical results show that the Higgs mode mediated enhancement can be larger than 50%. We investigate how the renormalization of the interlayer coupling depends on the parameters of the optical field and discuss possible challenges brought by damping.

[1] G. Homann, J. G. Cosme, J. Okamoto, L. Mathey, Phys. Rev. B 103, 224503 (2021)

TT 5.14 Mon 13:30 P

Optimization of Sr_2RuO_4 thin films grown by pulsed laser deposition — •Priyana Puliyappara Babu, Roman Hartmann, Alfredo Spuri, Sohaila Zaghloul Nabi Mohammed, Elke Scheer, and Angelo Di Bernardo — University of Konstanz, 78457 Konstanz, Germany

Since its discovery in 1994, $Sr_2RuO_4$4 has been the subject of intensive studies aiming at shedding light on the nature of its superconducting order parameter (OP). Despite earlier reports suggesting an unconventional nature of the Sr_2RuO_4 superconductivity, conflicting results have been recently reported and a definitive conclusion about the superconducting OP symmetry has not been yet achieved. To address some of the open questions, it is crucial to fabricate superconducting devices based on high-quality superconducting thin films of Sr_2RuO_4. However, this task has proven challenging due the sensitivity of Sr_2RuO_4 to disorder and impurities. We have carried out a systematic study to optimize the transport properties of Sr_2RuO_4 thin films grown by pulsed laser deposition using Sr_3RuO_7 single crystals as the material source. Thin films with very low density of defects, high residual resistivity ratio (> 20) and fully metallic down to low temperatures have been grown. The growth parameters that can be further optimized to get fully superconducting thin films have also been identified.

TT 5.15 Mon 13:30 P

Spin torque in a Josephson junction between two superconducting magnetic impurity states — •Fabian Ziesel[1], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Germany — [2]Institute of Quantum Tech-

nologies, German Aerospace Center (DLR), Ulm, Germany

Superconducting tunneling between spin-polarized Yu-Shiba-Rusinov (YSR) impurity states can be realized using a functionalized mK-STM [1], which can be further developed as a local probe of electronic spins for spintronics applications. Here, we consider a Josephson junction containing two magnetic impurities and show that the Josephson current is spin-dependent and accompanied by a spin torque. The torque acts to align the two impurities either parallel or anti-parallel, depending on the parity of YSR states occupation.
Using standard Green's functions techniques, we derive the spin-torque and spin-current as function of the superconducting phase difference ϕ and the relative angle θ between the impurity spins, modeled as classical magnets. Our results are also relevant for recent realizations of double quantum dot superconducting junctions with YSR states [2]. Finally, we provide a discussion on spin dynamics with a possible relevance to spin chains that show topological superconductivity.

[1] H. Huang *et al.*, Nat. Phys. **16**, 1227 (2020)
[2] J.C.E. Saldaña *et al.*, Phys. Rev. Lett. **121**, 257701 (2018)

TT 5.16 Mon 13:30 P

Fluxoid dynamics in high impedance long Josephson junctions — •Micha Wildermuth[1], Lukas Powalla[1], Jan Nicolas Voss[1], Yannick Schön[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2,3] — [1]Institute of Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia

The dynamics of Josephson vortices in long Josephson junctions is a well-known example of soliton physics and allows to study highly nonlinear effects on a mesoscopic scale. We experimentally study the characteristics of a Josephson junction with electrodes having a large kinetic inductance fraction which provides an additional degree of freedom. The London penetration depth exceeds the stack thickness which results in an incomplete screening of magnetic fields and in fluxoids with an altered shape. We present transport measurements of long Josephson junctions with electrodes made from disordered oxidized aluminum showing current steps with and without external magnetic fields and the IV-characteristics resemble the Fiske and zero-field steps. Magnetic field dependent measurements also show a very similar behavior to conventional long Josephson junctions.

TT 5.17 Mon 13:30 P

Exponential speedup of incoherent tunneling via dissipation — •Dominik Maile[1,2,4], Sabine Andergassen[2], Wolfgang Belzig[1], and Gianluca Rastelli[3] — [1]Fachbereich Physik, Universität Konstanz — [2]Institut für Theoretische Physik and Center for Quantum Science, Universität Tübingen — [3]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento — [4]Institut für komplexe Quantensysteme, Universität Ulm

We study the escape rate of a particle in a metastable potential in the presence of a dissipative bath coupled to the momentum of the particle. Using the semiclassical bounce technique, we find that this rate is exponentially enhanced. In particular, the influence of momentum dissipation depends on the slope of the barrier that the particle is tunneling through. We investigate also the influence of dissipative baths coupled to the position, and to the momentum of the particle, respectively. In this case the rate exhibits a nonmonotonic behavior as a function of the dissipative coupling strengths. Remarkably, even in the presence of position dissipation, momentum dissipation can enhance exponentially the escape rate in a large range of the parameter space. Our theoretical findings can be directly tested in superconducting quantum circuits in which dissipative position and momentum interactions translate to dissipative phase or charge couplings. In particular, momentum/charge dissipation can be readily implemented simply using capacitances and resistances.

TT 5.18 Mon 13:30 P

Electron cooling by phonons in mesoscopic superconducting systems — •Danilo Nikolic[1], Denis M. Basko[2], and Wolfgang Belzig[1] — [1]Fachbereich Physik, Universität Konstanz, D-78467 Konstanz, Germany — [2]Université Grenoble Alpes and CNRS, LPMMC, 25 Rue des Martyrs, 38042 Grenoble, France

We investigate the electron-phonon cooling power in disordered electronic systems with a special focus on mesoscopic superconducting proximity structures. Employing the quasiclassical Keldysh Green's function method, we obtain a general expression for the cooling power perturbative in the electron-phonon coupling but valid for arbitrary electronic systems out of equilibrium. We apply our theory to several disordered electronic systems valid for an arbitrary relation between the thermal phonon wavelength and the electronic mean-free path due to impurity scattering. In addition to recovering the known results for bulk normal metals and BCS superconductors, we consider two experimentally relevant geometries of superconductor-normal-metal proximity contacts. Both structures feature a significantly suppressed cooling power at low temperatures related to the existence of a minigap in the quasiparticle spectrum. This improved isolation low cooling feature in combination with the high tunability makes such structures highly promising candidates for quantum calorimetry.

This project has received funding from the EU Horizon 2020 program (Marie Sklodowska-Curie action QuESTech 766025).

[1] D. Nikolić, D. M. Basko, W. Belzig, Phys. Rev. B **102**, 214514 (2020)

TT 5.19 Mon 13:30 P

Charge dynamics in quantum-circuit refrigeration: thermalization and microwave gain — •Hao Hsu and Gianluigi Catelani — JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, Jülich, Germany

Recently, a quantum circuit refrigerator (QCR) consisting of a voltage biased superconductor-insulator-normal metal-insulator-superconductor (SINIS) tunnel junction has been experimentally demonstrated to cool superconducting resonators [1] and theoretically predicted to reset superconducting qubits [2] fast and accurately. Here we derive a master equation for a QCR-two level system dynamics. We find that starting with a steady state charge distribution on the normal-metal island, thanks to slower charge relaxation rate than the bare qubit decoherence rate at the off mode and the QCR-induced qubit decay rate, it always remains in its steady state, thus validating the former-presented theory [2, 3]. Replacing the normal-metal island with a quantum dot, we find a voltage regime where the photon-assisted tunnelings serve as a pumping mechanism. Also using the master equation approach, we investigate the possible microwave gain application by coupling the quantum dot QCR to a resonator.

[1] K. Y. Tan et.al., Nat. Commun. 8 15189 (2017)
[2] H. Hsu et.al., Phys. Rev. B 101, 235422 (2020)
[3] M. Silveri et.al., Phys. Rev. B 96, 094524 (2017)

TT 5.20 Mon 13:30 P

Heat transport in quantum overdamped systems — •sadeq s. kadijani, thomas l. schmidt, massimiliano esposito, and nahuel freitas — Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg

In classical and statistical physics, the overdamped limit of systems interacting with their environments is a very useful approximation allowing for the simplification of the Fokker-Plank equation in phase space to the Smoluchowski equation for the position variable alone. For quantum systems, the same limit leads to the quantum version of the Smoluchowski equation for systems in thermal equilibrium with only one thermal bath. However, to study the stochastic and quantum thermodynamics, one needs to deal with systems in a nonequilibrium situation where the quantum Smoluchowski equation is not valid anymore.

We are interested in studying the properties of the heat current in the overdamped limit where dissipation dominates. We obtain an analytical expression for the heat current between two overdamped quantum oscillators interacting with local thermal baths at different temperatures. The total heat current is split into classical and quantum contributions. We show how to evaluate both contributions by taking advantage of the timescale separation associated with the overdamped regime and without assuming the usual weak-coupling and Markovian approximations. We find that nontrivial quantum corrections survive even when the temperatures are high compared to the frequency scale relevant for the overdamped dynamics of the system.

TT 5.21 Mon 13:30 P

Emission of photon multiplets by a dc-biased superconducting circuit — •Björn Kubala[1,2], Gerbold Menard[3], Ambroise Peugeot[3], Ciprian Padurariu[2], Chloe Rolland[3], Zubair Iftikhar[3], Yuri Mukharsky[3], Carles Altimiras[3], Helene le Sueur[3], Philippe Joyez[3], Denis Vion[3], Patrice Roche[3], Daniel Esteve[3], Joachim Ankerhold[2], and Fabien Portier[3] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]ICQ and IQST, Ulm University, Germany — [3]SPEC, CEA Paris-Saclay, France

We show experimentally that a dc-biased Josephson junction in series with a high-impedance microwave resonator can emit up to $k = 6$ photons simultaneously for each Cooper pair tunneling through the junction. Our resonator is made of a simple micro-fabricated spiral coil that resonates at 4.4 GHz and reaches a 1.97 kΩ characteristic impedance, corresponding to an effective fine-structure constant, $\alpha \sim 1$. Measuring the second order correlation function of the emission from the resonator allows computing the Fano factor F of the emitted photons, found to coincide with the naive prediction $F = k$ in the weak driving regime. At higher emission, the feedback of the population of the resonator on the emission dynamics yields a non-monotonous behavior, hallmark of parametric transitions. Results are found in quantitative agreement with our theoretical predictions. This simple scheme highlights the ability of superconducting devices operating in the microwave domain to reach strong-coupling regimes of matter-light coupling inaccessible to conventional quantum optics experiments in the visible domain.

TT 5.22 Mon 13:30 P

Microwave photonics in High Kinetic Inductance Microstrip Networks — •Niklas Gaiser[1], Samuel Goldstein[2], Guy Pardo[2], Naftali Kirsh[2], Ciprian Padurariu[1], Björn Kubala[1,3], Nadav Katz[2], and Joachim Ankerhold[1] — [1]ICQ and IQST, University of Ulm, Ulm, Germany — [2]The Racah Institute of Physics, The Hebrew University of Jerusalem, Israel — [3]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Microwave photonics based on superconducting circuits is a promising candidate for many quantum-technological applications. Progress towards compact integrated photonics devices in the microwave regime, however, is constrained by their long wavelengths.

Here, we discuss a solution to these difficulties via compact networks of high-kinetic inductance microstrip waveguides and coupling wires with strongly reduced phase velocities experimentally realized in [1]. We describe, how the Kirchhoff equations of a periodic network map to a tight-binding model, which allows a description in term of Bloch waves and band structures, to explain experimental features. Furthermore, we present first steps towards exploiting versatility and unique properties of this new platform - compactness and reduced speed of light, strong nonlinear features, and band-structure design - to develop fundamental building blocks for integrated microwave photonics for technology applications and for exploring fundamental physics in such diverse areas as non-linear waves and topological lattice phases.

[1] S. Goldstein, G. Pardo, N. Kirsh, N. Gaiser, C. Padurariu, B. Kubala, J. Ankerhold, and N. Katz, arXiv:2106.15951

TT 5.23 Mon 13:30 P

Quantum Locking and Synchronization in Josephson Photonics Devices — •Florian Höhe[1], Lukas Danner[1,2], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Phase stability is an important characteristic of radiation sources. For quantum sources exploitation and characterization of many quantum properties, such as entanglement and squeezing, may be hampered by phase instability. Josephson photonics devices, where microwave radiation is created by inelastic Cooper pair tunneling across a *dc-biased* Josephson junction connected in-series with a microwave resonator are particularly vulnerable lacking the reference phase provided by an ac-drive. To counter this issue, sophisticated measurement schemes have been used in [1] to prove entanglement, while in [2] a weak ac-signal was put in to lock phase and frequency of the emission.

Here, we extend a recent classical theory [3] to describe locking and the synchronization of several Josephson-photonics devices to the quantum regime. Our description relies on linking the current shot-noise at a residual in-series resistor, which is crucial for phase diffusion, to the Full Counting Statistics of emitted radiation. From this full numerical description, phenomenological Adler-type equations for locking are derived to analyze quantum locking and synchronization.

[1] A. Peugeot et al., Phys. Rev. X 11, 031008 (2021).
[2] M. C. Cassidy et al., Science 355, 939 (2017).
[3] L. Danner et al., arXiv:2105.02564 (see also contribution here).

TT 5.24 Mon 13:30 P

Injection locking and synchronization in Josephson photonics devices — •Lukas Danner[1,2], Ciprian Padurariu[2], Joachim Ankerhold[2], and Björn Kubala[1,2] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]ICQ and IQST, Ulm University, Ulm, Germany

Injection locking can stabilize a source of radiation, leading to an efficient suppression of noise-induced spectral broadening and therefore, to a narrow spectrum. The technique is well established in laser physics, where a phenomenological description due to Adler is usually sufficient. Recently, locking experiments were performed in Josephson photonics devices, where microwave radiation is created by inelastic Cooper pair tunneling across a dc-biased Josephson junction connected in-series with a microwave resonator. An in-depth theory of locking for such devices however is lacking.

Here, we study injection locking in a typical Josephson photonics device where the environment consists of a single mode cavity, operated in the classical regime [1]. We show that an in-series resistance, however small, is an important ingredient in describing self-sustained Josephson oscillations and enables the locking region. We derive a dynamical equation describing locking, similar to an Adler equation, from the specific circuit equations. Phase slips due to noise are also studied. The synchronization of two Josephson photonics devices can be described by the Kuramoto model. For an extension of this classical analysis to the quantum regime, see the contribution by F. Höhe.

[1] L. Danner et al., arXiv:2105.02564 (submitted to PRB).

TT 5.25 Mon 13:30 P

Characterization of harmonic modes and parasitic resonances in multi-mode superconducting coplanar resonators — •Cenk Beydeda, Konstantin Nikolaou, Marius Tochtermann, Nikolaj G. Ebensperger, Gabriele Untereiner, Ahmed Farag, Philipp Karl, Monika Ubl, Harald Giessen, Martin Dressel, and Marc Scheffler — Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany

Planar superconducting microwave transmission line resonators can be operated at multiple harmonic resonance frequencies, which allows covering wide spectral regimes with high sensitivity, as is desired e.g. for cryogenic microwave spectroscopy. A common complication of such experiments is the presence of undesired “spurious” additional resonances. Identifying the nature of individual resonances (“designed” vs. “spurious”) can become challenging for higher frequencies or if elements with unknown material properties are included, as is common for microwave spectroscopy. Here various experimental strategies are discussed to distinguish designed and spurious modes in a broad frequency range up to 20 GHz. These strategies include tracking resonance evolution as a function of temperature, magnetic field, and microwave power. It is also demonstrated that applying minute amounts of dielectric or ESR(electron spin resonance)-active materials on the resonator lead to characteristic signatures in the various resonance modes, which depend on the local strength of the electric or magnetic microwave fields.

TT 5.26 Mon 13:30 P

Josephson Optomechanics — •Surangana Sen Gupta[1], Björn Kubala[1,2], Ciprian Padurariu[1], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Optomechanics at optical frequencies typically uses sources of light in a classical state, e.g. coherent states from lasers, to control mechanical vibrations. Cavity optomechanics can also be realised in the microwave regime using superconducting cavities and Josephson junctions. Inelastic tunneling in a Josephson junction biased by a dc-voltage can provide a bright source of quantum states of light, that can then be used for optomechanics. Experiments [1] have shown that the nonlinearity of Josephson junctions allows for various photon creation processes including single photon and multi-photon resonances.

Here, we theoretically investigate an optomechanical system consisting of a single-mode superconducting cavity, which is parametrically driven by a dc-biased Josephson junction at the two-photon resonance, and a mechanical resonator. The optomechanical coupling is treated in the spirit of mean field where the cavity is deep in the quantum regime, while the mechanics is considered semi-classical. We show that squeezed microwaves lead to regimes of heating and cooling for the mechanics and identify their signatures in the spectrum. We contrast these signatures with those of conventional optomechanics.

[1] M. Hofheinz, F. Portier, Q. Baudouin, P. Joyez, D. Vion, P. Bertet, P. Roche, D. Esteve, Phys. Rev. Lett. **106**, 217005 (2011)

TT 5.27 Mon 13:30 P

Transmission spectra of the driven, dissipative Rabi model in the USC regime — •Luca Magazzu[1], Pol Forn-Diaz[2,3,4], and Milena Grifoni[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institut de Física d'Altes Energies (IFAE) — [3]The Barcelona Institute of Science and Technology (BIST), Bellaterra (Barcelona) 08193, Spain — [4]Qilimanjaro Quantum Tech SL, Barcelona, Spain

We present theoretical transmission spectra of a strongly driven, damped, flux qubit coupled to a dissipative resonator in the ultrastrong coupling regime. Such a qubit-oscillator system, described within a dissipative Rabi model, constitutes the building block of super-conducting circuit QED platforms. The addition of a strong drive allows one to characterize the system properties and study novel phenomena, leading to a better understanding and control of the qubit-oscillator system. The calculated transmission of a weak probe field quantifies the response of the qubit, in frequency domain, under the influence of the quantized resonator and of the strong microwave drive. We find distinctive features of the entangled driven qubit-resonator spectrum, namely resonant features and avoided crossings, modified by the presence of the dissipative environment. The magnitude, positions, and broadening of these features are determined by the interplay among qubit-oscillator detuning, the strength of their coupling, the driving amplitude, and the interaction with the heat bath. This work establishes the theoretical basis for future experiments in the driven ultrastrong coupling regime.

[1] arXiv:2104.14490 (2021)

TT 5.28 Mon 13:30 P

Probing the Density of States of Defects in Superconducting Flux Qubits — •Benedikt Berlitz[1], Alexander Neumann[1], Alexey V. Ustinov[1,2,3], and Jürgen Lisenfeld[1] — [1]Physikalisches Institut Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany) — [2]National University of Science and Technology MISIS, Moscow, Russia — [3]Russian Quantum Center, Skolkovo, Moscow, Russia

Material defects forming two-level-systems (TLS) present a source of decoherence and unwanted degrees of freedom in superconducting quantum systems. Current theoretical models make different assumptions about the frequency dependence of the TLS' density-of-states (DOS). We intend to measure the TLS' DOS in a wide frequency range, spanning ~0.1 to 20 GHz, using widely tunable flux-qubits specifically designed as TLS-scanners. Measuring the DOS will enhance our understanding of the underlying physics of TLS in amorphous materials.

TT 5.29 Mon 13:30 P

Two-qubit gates between two transmons via parametrically driven coupling circuits — •Miriam Resch[1,2], Aneirin J. Baker[3], and Michael J. Hartmann[1,4] — [1]Physics Department, Friedrich-Alexander-University Erlangen Nürnberg, Germany — [2]ICQ and IQST, Ulm University, Germany — [3]Institute of Photonics and Quantum Sciences, Heriot-Watt University Edinburgh EH14 4AS, United Kingdom — [4]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

One important ingredient of quantum computation is the ability to implement gates that are efficient as well as precise to perform various operations on qubits. In the case of superconducting qubits, two-qubit gates can be implemented using a tunable coupler, where interaction terms in the Hamiltonian can be turned on and off. In this work we study the effective coupling of two transmon qubits through a coupler whose parameters are externally driven with a frequency ω_D. Depending on the drive frequency, the excitation number conserving interaction of an iSWAP gate, $\sigma_1^+\sigma_2^- + \sigma_1^-\sigma_2^+$, or the interaction of a bSWAP gate, $\sigma_1^+\sigma_2^+ + \sigma_1^-\sigma_2^-$, which does not conserve excitation numbers, can be created. Using an approach that considers the time dependent magnetic modulation of the coupler in a non-perturbative way, we find that the interaction of the bSWAP gate can be realized by driving the system with the average of the two qubit transition-frequencies. This result eliminates the demand for external drives at frequencies above 6 or 7 GHz for realizing interactions that break excitation number conservation and can thus realize bSWAP gates.

TT 5.30 Mon 13:30 P

Nuclear Spin Readout in a Cavity-Coupled Hybrid Quantum Dot-Donor System — •Jonas Mielke[1], Jason R. Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, Konstanz D-78457, Germany — [2]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

Nuclear spins show long coherence times and are well isolated from the environment, which are properties making them promising for quantum information applications. Here, we present a method for nuclear spin readout by probing the transmission of a microwave resonator. We consider a single electron in a silicon quantum dot-donor device interacting with a microwave resonator via the electric dipole coupling and subjected to a homogeneous magnetic field and a transverse magnetic field gradient. In our scenario, the electron spin interacts with a ^{31}P defect nuclear spin via the hyperfine interaction. We theoretically investigate the influence of the P nuclear spin state on the microwave transmission through the cavity and show that nuclear spin readout is feasible with current state-of-the-art devices. Moreover, we identify optimal readout points with strong signal contrast to facilitate the experimental implementation of nuclear spin readout.

TT 5.31 Mon 13:30 P

Bose condensation of squeezed light — •Klaus Morawetz — Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics-UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil

Light with an effective chemical potential and no mass is shown to possess a general phase-transition curve to Bose-Einstein condensation. This limiting density and temperature range is found by the diverging in-medium potential range of effective interaction. While usually the absorption and emission with Dye molecules is considered, here it is proposed that squeezing can create also such an effective chemical potential. The equivalence of squeezed light with a complex Bogoliubov transformation of interacting Bose system with finite lifetime is established with the help of which an effective gap is deduced. This gap phase creates a finite condensate in agreement with the general limiting density and temperature range. The phase diagram for condensation is presented due to squeezing and the appearance of two gaps is discussed.

[1] Phys. Rev. B 99 (2019) 205124

TT 5.32 Mon 13:30 P

Collisionless drag for a one-dimensional two-component Bose-Hubbard model — •Daniele Contessi[1,4], Donato Romito[2,3], Matteo Rizzi[4,5], and Alessio Recati[1,2] — [1]Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy — [2]INO-CNR BEC Center, 38123 Povo, Italy — [3]Mathematical Sciences, University of Southampton, Highfield, Southampton, SO17 1BJ, United Kingdom — [4]Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), 52425 Jülich, Germany — [5]Institute for Theoretical Physics, University of Cologne, D-50937 Köln, Germany

We theoretically investigate the elusive Andreev-Bashkin collisionless drag for a two-component one-dimensional Bose-Hubbard model on a ring. By means of Tensor Network algorithms, we calculate superfluid stiffness matrix as a function of the interactions and of the lattice filling. We focus on the region close to the so-called pair-superfluid phase, where we observe that the drag can become comparable with the total superfluid density. We elucidate the importance of the drag in determining the long-range behavior of the correlation functions and the spin speed of sound. In this way we are able to provide an expression for the spin Luttinger parameter K_S in terms of drag and the spin susceptibility. Our results are promising in view of implementing the system by using ultra-cold Bose mixtures trapped in deep optical lattices. Importantly the mesoscopicity of the system appears to favour a large drag, avoiding the Berezinskii-Kosterlitz-Thouless jump at the transition to the pair superfluid phase which would reduce the region where a large drag can be observed.

TT 6: Focus Session: Emerging Phenomena in Superconducting Low Dimensional Hybrid Systems I

Low-dimensional superconducting hybrid systems belong to the most intensively studied nanoelectronic devices and building blocks to date. On one hand they reveal and allow to study in detail a plethora of novel transport phenomena discovered only recently. These include, among others, studies of stacked two-dimensional hybrid systems, phenomena arising from the interplay between superconducting and magnetic order, single-particle or spin excitations excitations in zero- or one-dimensional systems, the competition of superconductivity and charging phenomena, Majorana bound states, or Ising superconductivity. On the other hand, some of these novel phenomenal are already under discussion for quantum information applications. This focus session aims at addressing selected aspects of the field thereby mainly focussing on the fundamental physical mechanisms rather than on the application aspects.

Organizers: Elke Scheer and Wolfgang Belzig (Konstanz University)

Time: Tuesday 10:00–12:45 Location: H7

Invited Talk TT 6.1 Tue 10:00 H7
Spin Triplet Superconductivity within Superconductors as Determined by FMR Spin pumping — •Lesley Cohen — Blackett Laboratory Imperial College London

Superconductor (SC)/ ferromagnet (FM) interfaces are of great interest as potential candidates to exploit the spin degree of freedom in superconducting phenomena, leading to potential applications for cryogenic memory and novel computing technologies. Over the last decade, experimental and theoretical studies have established that long-range spin polarized triplet supercurrents can be generated in superconducting/ferromagnetic heterostructures in the presence of magnetic inhomogeneities (e.g. spatially varying magnetization) via the proximity effect in combination with spin mixing and spin rotation processes. Separately it has been predicted that spin-orbit coupling in combination with the ferromagnetic exchange interaction can also generate conditions for the formation of spin triplet superconductivity. In this talk I will introduce the use of ferromagnetic resonance to inject a pure spin current in an interfacial material in close proximity, when that material is a superconductor. At a clean interface spin currents should be blocked from entering the superconductor by the Andreev process. I will discuss the conditions where the opposite appears to be the case and aspects we have learnt so far about using this technique to determine the strength of the spin triplet current within the superconductor under these conditions.

TT 6.2 Tue 10:30 H7
Tunneling Spectroscopy of Layered Superconductors — •Hadar Steinberg — Hebrew University of Jerusalem, Jerusalem, Israel

Tunnel junctions consisting of van der Waals (vdW) materials are realized by placement of thin barriers on top layered superconductors such as $NbSe_2$, TaS_2, and others. The atomic mating of the tunnel barrier and superconductor gives rise to a stable junction, which allows probing of the spectrum at high resolution, revealing clear signatures of the quasiparticle structure and of the sub-gap features. I will show how the use of such devices allows us to differentiate between dynamic properties of carriers in multi-gap superconductors. At ultrathin superconductors, we are able to track the evolution of the gap function up to very high in-plane magnetic field, where the gap feature hints at the onset of a triplet order. I will also show how defects in the barriers can give rise to quantum dot states, which can couple to the superconductor, forming Andreev bound states, and can be utilized as energy probes. Finally, I will show new data demonstrating the use of $NbSe_2$ as a source-drain electrode in a graphene-based Josephson device, which can sustain high in-plane fields.

15. min. break

TT 6.3 Tue 11:15 H7
Interplay of magnetism and Ising superconductivity: mirage gap and Josephson junction — •Gaomin Tang[1], Raffael L. Klees[2], Christoph Bruder[1], and Wolfgang Belzig[2] — [1]Department of Physics, University of Basel, Switzerland — [2]Fachbereich Physik, Universität Konstanz, Germany

Superconductivity is commonly destroyed by a magnetic field due to orbital or Zeeman-induced pair breaking. Surprisingly, the spin-valley locking in an Ising superconductor makes the superconducting state resilient to large magnetic fields. In the presence of an in-plane magnetic field, the emerging finite-energy pairing correlations manifest themselves in the occurrence of "mirage" gaps: at (high) energies of the order of the spin-orbit coupling strength, a gaplike structure in the spectrum emerges that mirrors the main superconducting gap. These mirage gaps are signatures of the equal-spin triplet finite-energy pairing correlations.

In a Josephson junction formed by two Ising superconductors that are in proximity to ferromagnetic layers, the supercurrent due to the triplet pairing correlations is controlled by the magnetic exchange fields. We show that both the charge and spin supercurrents can be modulated by the exchange fields.

[1] G. Tang, C. Bruder, W. Belzig, Phys. Rev. Lett. 126, 237001 (2021)

TT 6.4 Tue 11:30 H7
A Josephson junction supercurrent diode — •Christian Baumgartner[1], Lorenz Fuchs[1], Andreas Costa[1], Simon Reinhardt[1], Sergei Gronin[2], Geoffrey Gardner[2], Tyler Lindemann[2], Michael Manfra[2], Paulo Faria Junior[1], Denis Kochan[1], Jaroslav Fabian[1], Nicola Paradiso[1], and Christoph Strunk[1] — [1]University of Regensburg — [2]Purdue University

The combination of Rashba spin-orbit interaction and superconductivity leads to the appearance of an anomalous phase shift (φ_0) in the current phase relation (CPR) of Josephson junctions, as experimentally demonstrated by several groups in recent years. However, if the CPR is sinusoidal, the φ_0 shift does not affect the symmetry between positive and negative branch of the CPR. Here, we demonstrate that in short ballistic Josephson junctions application of an in-plane field perpendicular to the current induces an asymmetry between positive and negative branch of the CPR. Such magnetochiral anisotropy (MCA) is at the basis of the so-called supercurrent diode effect, here shown for the first time in Josephson junctions. We quantify MCA by measuring the kinetic inductance, whose in-plane field dependence allows us to determine the MCA coefficient for the superfluid. The experimental value compares well with the results of tight-binding simulations based on realistic material parameters for epitaxial Al/InAs 2DEGs.

TT 6.5 Tue 11:45 H7
Majorana bound states in magnetic impurity chains on conventional superconductors — •Annica Black-Schaffer — Uppsala University, Uppsala, Sweden

Magnetic impurities on the surface of spin-orbit coupled but otherwise conventional superconductors offer the possibility to create topological phases with Majorana bound states (MBSs) without having to apply an external magnetic field. In this talk I will present some of our resent results in modeling both magnetic impurity wires and islands on the surface of spin-orbit coupled superconductors, including a self-consistent treatment of the superconductivity, which results in a local π-shift of superconducting order parameter near magnetic impurities. In particular, I will show how MBSs at wire end points very strongly hybridize with in-gap Yu-Shiba-Rusinov (YSR) states, causing large oscillations in the MBSs energies that are significantly enhanced within the self-consistent treatment. Still, by treating the MBSs as topological boundary modes dependent only on the effective mass gap, we can arrive at a fully parameter-free fitting of the Majorana localization length, which stays very short. I will also show how the wire end point MBSs are very robust against disorder within a self-consistent treatment, despite individual YSR states being extremely sensitive to disorder. Finally, despite the importance of a self-consistent treatment of superconductivity for the properties of the MBSs, I will show how the π-shift cannot easily be measured using the Josephson effect.

TT 6.6 Tue 12:15 H7

Evidence for p-wave pairing and precursors of Majorana modes in artificial Shiba chains — •Jens Wiebe — Department of Physics, Universität Hamburg, Hamburg, Germany

Magnetic chains on s-wave superconductors hosting spin spirals or spin-orbit coupling may realize one-dimensional topological superconductors with Majorana modes on their edges. We study artificial spin chains built atom-by-atom [1] with respect to such phenomena. By variation of substrate and adatom species and interatomic distances in the chain [2-5], we adjust the energies of multi-orbital Yu-Shiba Rusinov states induced by the adatoms [2,3], their hybridizations [4], as well as the chains' spin structures [5]. This enables to tailor the emerging multi-orbital Shiba bands such that p-wave gaps open [6]. We measure the length dependent energy oscillations of precursors of Majorana modes in short chains [7].

We acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) via the Cluster of Excellence 'Advanced Imaging of Matter' (EXC 2056-project ID 390715994), via the SFB-925-project 170620586, and by the ERC via the Advanced Grant ADMIRE (No. 786020).

[1] D.-J. Choi *et al.*, Rev. Mod. Phys. **91**, 041001 (2019)
[2] L. Schneider *et al.*, npj Quantum Materials **4**, 42 (2019)
[3] L. Schneider *et al.*, Nature Commun. **11**, 4707 (2020)
[4] P. Beck *et al.*, Nat. Commun. **12**, 2040 (2021)
[5] L. Schneider *et al.*, Science Advances **7**, eabd7302 (2021)
[6] L. Schneider *et al.*, Nat. Phys. (2021) https://doi.org/10.1038/s41567-021-01234-y
[7] L. Schneider *et al.*, arXiv:2104.11503 (2021)

TT 7: Focus Session: Disordered and Granular Superconductors: Fundamentals and Applications in Quantum Technology II

Time: Tuesday 13:30–16:15 Location: H6

TT 7.1 Tue 13:30 H6

Granular Aluminum: a superconducting material with amenable nonlinearity for quantum circuits — •Ioan Pop — KIT, Karlsruhe, germany

The electrodynamics of granular Aluminum (grAl) can be modeled based on an effective Josephson junction array with high kinetic inductance and amenable nonlinearity[1,2]. This recommends grAl for various applications in quantum technology, including kinetic inductance detectors, parametric amplifiers and quantum bits. One illustration of grAl's utility in quantum circuit design is the remarkable resilience of grAl fluxonium qubits[3] to photons populating its dispersively coupled readout resonator. This resilience allows single shot QND measurements[4] and quantum state preparation via active feedback with fidelities exceeding 90

[1] Maleeva et al. Nature Comm. 9, 3889 (2018)
[2] Winkel et al. Phys. Rev. X 10, 031032 (2020)
[3] Grunhaupt, Spiecker et al. Nature Materials 18, 816-819 (2019)
[4] Takmakov, Winkel, et al. Phys. Rev. App. 15, 064029 (2021)
[5] Gusenkova, Spiecker, et al. Phys. Rev. App. 15, 064030 (2021)
[6] Cardani, Valenti et al. Nat. Commun. 12, 2733 (2021)

TT 7.2 Tue 14:00 H6

Novel Quantum state at the interface between graphene and disordered superconductor — •Gopi Nath Daptary, Eyal Walach, Efrat Shimshoni, and Aviad Frydman — Department of Physics, Bar-Ilan University, Ramat-Gan 5290002, Israel

Over the past decades, there have been considerable interest in electronic properties of low dimensional systems, in particular the quantum effects that manifest themselves as the dimensions of a device approaches a microscopic length scale. Two-dimensional (2D) materials, composed of single atomic layers, have attracted vast research interest since the breakthrough discovery of graphene. One major benefit of such systems is the simple ability to tune the Fermi level through the charge neutrality point between electron and hole doping. For 2D Superconductors, this means that one may potentially achieve the regime described by Bose Einstein Condensation (BEC) physics of small bosonic tightly bound electron pairs. In my talk I will describe an experiment showing that single layer graphene, in which superconducting pairing is induced by proximity to a low density superconductor, can be tuned from hole to electron superconductivity through an ultra-law carrier density regime. We have studied, both experimentally and theoretically, the vicinity of this "Superconducting Dirac point" and found an unusual situation where reflections at interfaces between normal and superconducting regions within the graphene, suppress the conductance. In addition, the Fermi level can be adjusted so that the momentum in the normal and superconducting regimes perfectly match giving rise to ideal Andreev reflection processes.

TT 7.3 Tue 14:15 H6

Impact of Kinetic Inductance on the Critical Curren Oscillations of Nanobridge SQUIDs — •Heleen Dausy, Lukas Nulens, Bart Raes, Margriet Van Bael, and Joris Van de Vondel — Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium

We study lithographically fabricated MoGe nanobridges and their current phase relation (CΦR), which is linked to the nanobridge kinetic inductance. We do this by imbedding the nanobridges in a SQUID. We observe that for temperatures far below the critical temperature, the CΦR is linear as long as the condensate is not weakened by the presence of supercurrent. Another result is that the nanobridge kinetic inductance scales with its aspect ratio. We demonstrate that the SQUID $I_c(B)$ characteristic is tuneable through lithographic control over the nanobridge dimensions. These observations can be of use for the design and operation of future superconducting devices such as magnetic memories or flux qubits.

TT 7.4 Tue 14:30 H6

Disorder-enhanced inelastic relaxation in thin NbN films — Andrey Lomakin[1,2], Elmira Baeva[1,2], Philipp Zolotov[1,2], Alexandra Triznova[2], •Anna Kardakova[1,2], and Gregory Goltsman[1,2] — [1]National Research University Higher School of Economocs, Moscow, Russia — [2]Moscow Pedagogical State University, Moscow, Russia

Disordered superconducting films is a building block for superconducting nanowire single-photon detectors. A complex physics of such detectors implies a non-equilibrium response, determined by energy relaxation of electrons, namely electron-phonon (e-ph) scattering and phonon escaping times. In practice, one prefers to reduce these values along with optimization of other detector parameters.

Here, we report on experimental study of inelastic relaxation in thin disordered NbN films by measuring of magnetoconductance in the temperature range $T_c < T < 3T_c$. The studied 2.5-nm thick NbN films are characterized by a moderate level of disorder, expressed as $3 < k_F l < 6$. From magnetoconductance data, we find out the phase-breaking rate is a sum of two terms, electron-electron (e-e) and e-ph scattering, $\tau_\phi^{-1} \sim A_{e-e}T + A_{e-ph}T^n$, where $n = 3.5 - 4$ is similar as in work of Sidorova et.al, 2020. We also observe that both e-e and e-ph rates gradually increase with film disorder. The trend for increase of e-e rate with disorder is consistent with scenario of fermionic suppression of superconductivity in NbN films.

15. min. break

TT 7.5 Tue 15:00 H6

Magnetic-field-compatible hybrid superconducting circuits — •Marta Pita-Vidal — Qutech, Delft university of Technology, The Netherlands

Hybrid superconducting circuits, which integrate semiconducting elements into a circuit quantum electrodynamics (cQED) architecture, provide new insights into mesoscopic superconductivity. Extending the capabilities of hybrid circuits to work in large magnetic fields would enable the investigation and control of spin-polarized and topological phenomena. Here, I will discuss our work on magnetic-field-compatible hybrid cQED devices based on NbTiN. In particular, we exploit the high kinetic inductance of thin NbTiN to build a fluxonium which includes an electrostatically-tuned semiconducting nanowire as its nonlinear element. We in-situ tune its Josephson energy with an electrostatic gate and demonstrate operation of the fluxonium in magnetic fields up to 1T. This combination of gate-tunability and field-compatibility demonstrates the utility of hybrid superconducting circuits for exploring mesoscopic physics and enables the use of the fluxonium as a readout device for topological qubits.

TT 7.6 Tue 15:30 H6

Disordered superconducting NbN thin films and their quantum device application — •Evgeni Il'ichev[1], Sven Linzen[1], Oleg Astafiev[2,3], Rais Shaikhaidarov[3], Kyungho Kim[3], Jacob Dunstan[3], Ilya Antonov[3], Vladimir Antonov[2,3], Mario Ziegler[1], Gregor Oelsner[1], and Ronny Stolz[1] — [1]Leibniz Institute of Photonic Technology, Jena, Germany — [2]Skolkovo Institute of Science and Technology, Bolshoy Boulevard 30, bld. 1, Moscow, Russia 121205 — [3]Physics Department, Royal Holloway, University of London, United Kingdom

Within the past years we optimized and studied the properties of superconducting niobium nitride films fabricated with plasma-enhanced atomic layer deposition (PEALD). The films are polycrystalline and consist mainly of cubic δ-niobium-nitride grains of only a few nanometers in size. A superconductor to insulator transition (SIT) can be observed within ultrathin PEALD-NbN films by reducing the film thickness from 3.1 to 2.8 nm. Well-adjusting the film thickness slightly above the SIT point the films show high values of the kinetic inductance and the normal state resistance. Such films were used to fabricate nanowires in which the coherent quantum phase slips (CQPS) can be observed. Observation of the Aharonov-Casher effect as well as the dynamics of the CQPS are discussed.

This work was supported by European Union Horizon 2020 Research and Innovation Programme under Grant No. 862660/QUANTUM E-LEAPS.

TT 7.7 Tue 15:45 H6

High-kinetic-inductance superconducting nanowires for ultra-compact microwave devices — •Marco Colangelo[1], Daniel F. Santavicca[2], Carleigh R. Eagle[2], Brenden A. Butters[1], Owen Medeiros[1], Maitri P. Warusawithana[2], and Karl K. Berggren[1] — [1]Massachusetts Institute of Technology, Department of Electrical Engineering and Computer Science, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA — [2]University of North Florida, Department of Physics, 1 UNF Dr, Jacksonville, FL 32224

Superconducting nanowires made of disordered thin films can achieve a kinetic inductance which is several orders of magnitude higher than their magnetic inductance. Nanowires, integrated into transmission-line architectures, feature a characteristic impedance ~kΩ, an effective phase velocity a few percent of the speed of light in vacuum, and a strong compression of the microwave wavelength. We exploit these properties to demonstrate a balanced forward coupler at 4.73GHz based on coupled nanowire stripline with < 500 μm2 footprint, more than one order of magnitude lower than traditional modules. Interfacing high-impedance nanowire devices to 50 Ω electronics requires a large matching structure, which can, in principle, spoil the miniaturization achieved with nanowires. We address this challenge by combining high-inductance nanowires with high dielectric constant substrates. We demonstrate nanoscale resonators operating natively at 50Ω featuring a wavelength compression of almost 200 times. This demonstration paves the way to 50Ω ultra-compact cryogenic microwave devices.

TT 7.8 Tue 16:00 H6

Eliminating Quantum Phase Slips in Superconducting Nanowires — •Jan Nicolas Voss[1], Yannick Schön[1], Micha Wildermuth[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2,3,4] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Institut für Quantenmaterialien und Technologien (IQMT), Karlrsruher Institut für Technologie, Karlsruhe, Germany — [3]Russian Quantum Center, Skolkovo, Moscow, Russia — [4]National University of Science and Technology MISIS, Moscow, Russia

Superconducting nanowires made from granular aluminium have unique electrical properties at low temperatures. They originate from the intrinsic network of Josephson junctions in the material and the spatial restrictions to dimensions that are of the order of the superconducting coherence length. We present a novel method, which allows changing the nanowire resistance by modifying the intrinsic junction network by electrical pulses.

At low temperatures, we have observed a transition from an insulating over a metallic to a superconducting response in about a two hundred individual resistance steps. The measurement results are compared with the quantum phase slip model for superconducting nanowires [1].

[1] J. N. Voss, Y. Schön, M. Wildermuth, D. Dorer, J. H. Cole, H. Rotzinger and A. V. Ustinov, ACS Nano 15, 4108 (2021)

TT 8: Focus Session: Emerging Phenomena in Superconducting Low Dimensional Hybrid Systems II

Time: Tuesday 13:30–16:15 Location: H7

TT 8.1 Tue 13:30 H7

Theory of Shiba-Shiba tunneling at the edge of a Majorana chain — •Ciprian Padurariu[1], Haonan Huang[2], Björn Kubala[1,3], Christian R. Ast[2], and Joachim Ankerhold[1] — [1]Institute for Complex Quantum Systems and IQST, Ulm University, Ulm, Germany — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany — [3]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

The realization of the Majorana chain [1], a 1D-chain of Yu-Shiba-Rusinov (YSR) impurity states on the surface of a superconductor, suggests that Majorana states emerging at the edges can be probed by an STM. Recently, we have developed an ideal tool to probe and manipulate the edge states of a Majorana chain. It consists of a superconducting STM tip functionalized with its own in-gap YSR state created by a magnetic impurity on the tip. With this device we have studied the sharp resonant transport between the YSR state on the tip and another YSR on the sample, and have developed its theory [2].

This presentation will expand on the theory of Shiba-Shiba tunneling and present the possibilities to manipulate edge states of the Majorana chain. In certain parameter regimes theory predicts that the edge state will transfer from the chain to the tip. This may provide a first step towards realizing braiding of edge states using the STM.

[1] S. Nadj-Perge, *et al.*, Science **346**, 602 (2014)
[2] H. Huang, *et al.*, Nat. Phys. **16**, 1227 (2020)

TT 8.2 Tue 13:45 H7

Spin-polarized zero bias peak from a single magnetic impurity at a s-wave superconductor — •Kyungwha Park[1], Bendeguz Nyari[2], Andras Laszloffy[3], Laszlo Szunyogh[2], and Balazs Ujfalussy[3] — [1]Virginia Tech, Blacksburg, United States — [2]Budapest University of Technology and Economics, Budapest, Hungary — [3]Wigner RCP, ELKH, Budapest, Hungary

Topological superconductivity has emerged a promising platform for quantum computing using Majorana modes. Since intrinsic topological superconductors are rare, various heterostructures including ferromagnetic atomic chains on s-wave superconductors have been proposed to realize topological superconductivity. So far, most theoretical studies in heterostructures were done using effective models. Here we investigate the Yu-Shiba-Rusinov (YSR) states of a single magnetic impurity at the surface of superconducting Pb using the fully relativistic first-principles simulations including DFT band structure of Pb and 3d orbitals of the impurity in the superconducting state. For the single Fe and Co impurities, we observe strong effects of spin-orbit coupling on the YSR states as the impurity moment rotates. As the rotation angle varies, we show that two symmetric same-spin YSR states of electron character merge and form a zero-bias peak (ZBP) with large spin polarization. According to effective models, whether a ZBP has net spin polarization or not is often used to determine its topological nature. Our results reveal importance of including realistic band structure and multiple 3d orbitals of the impurity in the calculations.

TT 8.3 Tue 14:00 H7

Conductance anomalies in magnetization-controlled superconductor-ferromagnet-superconductor proximity junctions — •Lukas Kammermeier, Elke Scheer, Angelo di Bernardo, and Maik Kerstingskötter — Universität Konstanz, Konstanz, Germany

A key building block in superconducting spintronics is a controllable superconducting spin triplet device. We study superconducting aluminium contacts, the superconducting properties of which are locally modulated by the inverse proximity effect of an adjacent ferromagnet (cobalt in this case). We show that the zero-field current-voltage characteristics of these devices can be in situ controlled by polarizing the magnet in a parallel magnetic field.

The measurements reveal that we can drive the system into different conductance states controlled by the magnetization state of the ferromagnet. One of these states shows a significant differential conductance increase, which even increases more while the magnetic field is applied, possibly indicating a spin-triplet-dominated transport regime.

TT 8.4 Tue 14:15 H7

Heat-charge separation and nonlocal response in superconductor-InAs nanowire hybrid devices — Artem Denisov[1], Gregor Koblmueller[2], and •Vadim Khrapai[3] — [1]Department of Physics, Princeton University, Princeton — [2]Walter Schottky Institut, Physik Department, and Center for Nanotechnology and Nanomaterials, TU Muenchen — [3]Osipyan Institute of Solid State Physics of the Russian Academy of Sciences

Nonlocal quasiparticle transport in normal-superconductor-normal (NSN) hybrid structures probes sub-gap states in the proximity region. Here we show that a non-local shot noise is a complementary to conductance measurement in superconducting proximity devices. Using NSN InAs nanowire based devices we demonstrate that quasiparticle response is practically charge-neutral. This is qualitatively explained by numerous Andreev reflections of a diffusing quasiparticle, that makes its charge completely uncertain. As a result, the sub-gap response is dominated by the heat transport component with a thermal conductance being on the order of the conductance quantum. By contrast, strong fluctuations and sign reversal are observed in the nonlocal conductance, including occasional Andreev rectification signals. Our results evidence effective heat-charge separaion at the central S-terminal.

We are grateful to our colleagues A. Bubis, S. Piatrusha, N. Titova, A. Nasibulin, J. Becker, J. Treu, D. Ruhstorfer and E. Tikhonov for their contribution to the preprint arXiv:2101.02128 on which this presentation is based.

15 min. break

TT 8.5 Tue 14:45 H7

Supercurrent-enabled Andreev reflection in a chiral quantum Hall edge state — •Andreas Bock Michelsen[1,2], Patrik Recher[3], Bernd Braunecker[1], and Thomas Schmidt[2] — [1]SUPA, School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews KY16 9SS, UK — [2]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg — [3]Institut für Mathematische Physik, Technische Universität Braunschweig, 38106 Braunschweig, Germany

A chiral, spinless quantum Hall edge state placed in proximity to an s-wave superconductor experiences induced superconducting correlations. This effect provides a promising pathway to the realization of Majorana zero-modes and their parafermionic generalizations as non-Abelian anyons. Recent experiments have observed the phenomenon through conductance signatures of the mediating process of Andreev reflection, where electrons tunnel in pairs. We develop a tunneling model of the system and demonstrate that this process is enabled by the superconductor surface hosting spin-orbit coupling and a supercurrent induced by the strong magnetic field. By integrating out the superconductor we develop an effective model of the proximitized edge state, and derive an expression for the probability of an electron being transported as a hole through the edge state. This lets us analytically predict the outcome of conductance measurements given external experimental parameters.

TT 8.6 Tue 15:00 H7

Majorana zero modes in one- and two-dimensional magnet-superconductor hybrid systems — •Stephan Rachel — School of Physics, University of Melbourne, Parkville, VIC 3010, Australia

Majorana zero modes, exotic quasiparticles in topological superconductors, are considered as the fundamental building blocks of future fault-tolerant quantum computers. The list of candidate materials is, however, short. Magnet-superconductor hybrid (MSH) systems represent one of the most promising platforms for topological superconductivity: magnetic atoms are placed on the surface of a conventional superconductor with spin-orbit coupling, leading to a topologically nontrivial system. Here we report recent theoretical progress on one- and two-dimensional MSH systems, and discuss them in the light of the latest experiments. By combining ab initio modeling and toy-model calculations on the theoretical side with atom-manipulation techniques via STM on the experimental side, we are getting closer to a complete understanding of Majorana zero modes in MSH systems.

TT 8.7 Tue 15:15 H7

Josephson and Andreev transport in a superconducting single electron transistor with a normal lead (SSN-SET) — •Laura Sobral Rey[1,2] and Elke Scheer[1,2] — [1]Physics department, University of Konstanz, 78464, Konstanz, Germany — [2]QuESTech consortium

An island coupled via a tunnel barrier to two leads and a gate forms a single electron transistor (SET) that shows Coulomb blockade. All-superconducting SETs (SSS-SETs) have shown to enable a multitude of possible charge transport processes which are not well understood, in particular in the strong-coupling regime [1]. To disentangle these processes, we study here the conceptually simpler SSN-SET, which has never been investigated experimentally before.

The SSN-SETs studied here consist of an S island coupled to an N lead via an oxide tunnel barrier, and to an S lead with a mechanically controlled break junction (MCBJ). Via the MCBJ, different coupling regimes can be studied: from a tunnel contact when the MCBJ is broken to a point contact when it is closed. In that limit the MCBJ has a small number of highly transmissive transport channels.

For weak coupling, our experimental findings can be understood in terms of the orthodox theory [2]. For stronger coupling, we observe Andreev and Josephson transport, as well as a renormalization of the charging energy and dynamical Coulomb blockade, which are also observed in the N state.

[1] T. Lorenz, J. Low Temp. Phys. 191, 301 (2017)
[2] T.A. Fulton, Phys. Rev. Lett. 59, 109 (1987)

TT 8.8 Tue 15:30 H7

Unconventional Meissner screening induced by chiral molecules in a conventional superconductor — Hen Alpern[1], Morten Amundsen[2], •Roman Hartmann[3], Nir Sukenik[1], Alfredo Spuri[3], Shira Yochelis[1], Thomas Prokscha[4], Vitaly Gutkin[1], Yonathan Anahory[1], Elke Scheer[3], Jacob Linder[2], Zaher Salman[4], Oded Milo[1], Yossi Paltiel[1], and Angelo Di Bernardo[3] — [1]The Hebrew University of Jerusalem — [2]Norwegian University of Science and Technology — [3]Universität Konstanz — [4]Paul Scherrer Institut

Superconducting spintronics is emerging as an alternative technology that can overcome the main limitation of conventional spintronic devices, their high current dissipation. It has developed after the discovery that Cooper pairs with parallel-aligned spins (spin-triplets) can be generated at the interface between a conventional superconductor (S) and a magnetically inhomogeneous ferromagnet (F). More recently, by performing low-temperature scanning tunneling spectroscopy measurements of chiral molecules (ChMs) adsorbed on the surface of a Nb (S) thin film, we have observed subgap features due to spin-triplet states. Motivated by these results, we have performed low-energy muon spectroscopy on ChMs/Nb which shows evidence for an unconventional Meissner screening effect. Our experimental data and theoretical analysis show that the unconventional Meissner screening is due to the generation of spin-triplet pairs, as a result of the ChMs acting as a spin active interface. These results pave the way for the realisation of novel devices based on ChMs/S hybrids for superconducting spintronics.

TT 8.9 Tue 15:45 H7

Magic angles and current-induced topology in twisted nodal superconductors — •Pavel Volkov, Justin Wilson, and Jed Pixley — Rutgers University

We propose twisted bilayers of two-dimensional nodal superconductors as a new platform to realize topological and correlated superconducting phases. We show that the Fermi velocity of the Dirac excitations in the Bogoliubov-De Gennes quasiparticle dispersion is strongly renormalized by the interlayer hopping, vanishing at a "magic angle", where time-reversal breaking superconductivity is induced. We demonstrate that magnetic field, electric gating, and current bias can be used for versatile control of the system. In particular, an interlayer current bias opens a topological gap, with the system being characterized by a non-zero Chern number.

TT 8.10 Tue 16:00 H7

Vortex inductance as a probe of symmetry breaking in Rashba superconductors — •Lorenz Fuchs[1], Denis Kochan[1], Simon Reinhardt[1], Christian Baumgartner[1], Sergei Gronin[2], Geoffrey Gardner[2], Tyler Lindemann[2], Michael Manfra[2], Christoph Strunk[1], and Nicola Paradiso[1] — [1]University of Regensburg (Germany) — [2]Purdue University (USA)

In this work, we demonstrate the use of vortices as directional probes of the superconducting condensate symmetry via vortex inductance measurements. We investigate Al/InAs heterostructures containing a high-mobility InAs quantum well that is proximitized by the epitaxially grown Al top layer. In out-of-plane magnetic field, ac-current-driven oscillations of vortices around pinning centers give rise to an additional inductance, which is orders of magnitude larger than the bare kinetic inductance of the superfluid. We find that the application of an additional in-plane magnetic field induces a surprising increase of the pinning potential and demonstrate that such increase obeys a characteristic two-fold anisotropy when changing the angle between the in-plane field and the ac-current. The observed counter-intuitive behavior can be theoretically explained by introducing Lifshitz-invariant terms (resulting from the Rashba interaction and the in-plane field) in the Ginzburg-Landau free energy.

TT 9: Poster Session: Correlated Electrons

Time: Tuesday 13:30–16:00 Location: P

TT 9.1 Tue 13:30 P

Electronic Nematicity in 4f electron systems — •Mario Malcolms de Oliveira[1], Pascoal Pagliuso[2], and Eduardo Miranda[2] — [1]Max Planck Institute for Solid State Research — [2]Unicamp

In this work, we show that the interplay between the Neel order and the spin-orbit coupling present in 4f electron systems are key ingredients to give rise to the emergence of an electronic nematic state in this kind of system. Our result can shed light on the understanding of the experimental results observed for the heavy-fermion compound $CeRhIn_5$.

TT 9.2 Tue 13:30 P

Spin excitations in the fully gapped hybridized two band superconductor — •Alireza Akbari and Peter Thalmeier — Max Planck Institute for the Chemical Physics of Solids, D-01187 Dresden, Germany

In f-electron heavy fermion superconductors, the presence of a spin resonance in the inelastic magnetic response is commonly associated with an unconventional nodal gap function that is not fully symmetric. However, it appears possible that the resonance is still observed even when the low-temperature thermodynamic behavior suggests a fully gapped state. We investigate such possibility within a two-dimensional toy model of a hybridized superconductor with a fully symmetric unconventional symmetry with a different sign of the gap function on disjoint Fermi surface sheets. We compute the collective magnetic response function in the hybridized superconducting state of the two-band model and show that the appearance of the resonance is also possible for the fully gapped state.[1]

[1] A. Akbari, P. Thalmeier, Annals of Physics 428, 168433 (2021)

TT 9.3 Tue 13:30 P

Probing the electron-lattice coupling near the valence transition of $EuPd_2Si_2$ — •Jan Zimmermann, Steffi Hartmann, Bernd Wolf, Marius Peters, Cornelius Krellner, and Michael Lang — PI, SFB/TR288, Goethe Univ., Frankfurt/M., Deutschland

The thermodynamic properties of materials close to a second-order critical endpoint in strongly correlated electron systems are a field of high interest. Within the strong-coupling regime, it is expect to find cross-correlations between electronic and lattice properties like the recently proposed phenomena of critical elasticity, which implies a strong lattice softening and strongly nonlinear strain-stress relations. [1] Intermetallic compounds from the EuT_2X_2 family show various types of phase transitions such as valence- or structural instabilities that make it possible to study collective phenomena resulting from such a particularly strong coupling of electrons to phonons [2]. In this work electron lattice coupling near the second-order critical endpoint of the valence transition in $EuPd_2Si_2$ is investigated via thermodynamic methods. Recently published measurements [2] indicate the unique possibility of experimental access to the critical endpoint of the valence transition using helium gas pressure. We present measurements of thermal expansion and compressibility in a pressure range from 0 MPa up to 40 MPa and temperatures from 90 K to 210 K. Results are compared to specific heat measurements and analyzed for sample-to-sample variations.

[1] E. Gati *et al.*, Sci. Adv. **2**, e1601646 (2016)
[2] Y. Onuki *et al.*, Philosophical Magazine **97**, 3399 (2017)

TT 9.4 Tue 13:30 P

Magnetic and electronic phases of $U_2Rh_3Si_5$ — •Jannis Willwater[1], Nico Steinki[1], Dirk Menzel[1], Ricarda Reuter[1], Hiroshi Amitsuka[2], Vladimír Sechovsky[3], Michal Valiska[3], Marcelo Jaime[4], Franziska Weickert[5], and Stefan Süllow[1] — [1]TU Braunschweig, Braunschweig, Germany — [2]Hokkaido University, Sapporo, Japan — [3]Charles University, Prague, Czech Republic — [4]Los Alamos National Laboratory, Los Alamos, USA — [5]Florida State University, Tallahassee, USA

It has been demonstrated that the intermetallic uranium compound $U_2Rh_3Si_5$ exhibits a unique first-order antiferromagnetic transition accompanied by a structural transition. This was explained with the so-called bootstrapping effect. Here, we present a detailed study of the magnetic and electronic properties of this compound.

Based on the results of magnetization and magnetostriction measurements in high magnetic fields, we establish the complex magnetic phase diagram of $U_2Rh_3Si_5$ up to 60 T. For the first time, various steps in the high-field magnetization of the a axis have been observed. These effects are probably due to several metamagnetic transitions. In addition, the electrical resistivity exhibits a unique anomaly in a narrow temperature range above the Néel temperature. Since there is no associated signature in the magnetic susceptibility or the structural parameters for all three crystallographic axes, this anomaly in the resistivity cannot be caused by a magnetic, but rather by an electronic phase transition.

[1] J. Willwater et al., Phys. Rev. B **103**, 054408 (2021)

TT 9.5 Tue 13:30 P

Anisotropic magnetic and thermodynamic properties of single crystals of antiferromagnetic $CePdAl_3$ — •Vivek Kumar[1], Andreas Bauer[1], Christian Franz[2,3], Rudolf Schönmann[1], Michal Stekiel[1], Astrid Schneidewind[1], and Christian Pfleiderer[1] — [1]Physik-Department, Technische Universität München, D-85748 Garching, Germany — [2]JCNS at MLZ, FZ Jülich GmbH, Lichtenbergstr. 1, D-85747 Garching — [3]TUM at MLZ, Technische Universität München, D-85748 Garching, Germany

Recently, the class of $CeTAl_3$ (T is a transition metal) attracted considerable scientific attention when strong coupling between phonons and crystal electric field excitations was demonstrated in $CeCuAl_3$ and $CeAuAl_3$ [1,2]. Here, we report on the magnetic and thermodynamic properties of single-crystalline $CePdAl_3$ studied by means of ac susceptibility, magnetization, and specific heat measurements. The compound crystallizes in an orthorhombic crystal structure and displays antiferromagnetic order below $T_N = 5.6$ K. A strong anisotropy was observed in magnetic properties. We obtained a large electronic specific heat coefficient, $\gamma = 121$ mJ K^{-2} mol^{-1}, characteristic of heavy-fermion behavior. Field-driven magnetic transitions were detected for fields applied along the easy basal plane, which leads to a complex magnetic phase diagram.

[1] Franz *et al.*, J. Alloys Compd. **688**, 978 (2016).
[2] Čermák *et al.*, Proc. Natl. Acad. Sci. U.S.A. **116**, 6695 (2019).

TT 9.6 Tue 13:30 P

Low-Temperature Properties of the Non-Centrosymmetric Heavy-fermion Compound $CeAl_2$ — •Christian Oberleitner, Alexander Regnat, Christian Franz, Jan Spallek, Georg Benka, Michael Petrov, Marc Andreas Wilde, Andreas Bauer, and Christian Pfleiderer — Physik-Department, Technische Universitaet Muenchen, 85748 Garching, Germany

We report a comprehensive study of the non-centrosymmetric heavy-fermion compound $CeAl_2$ with $T_N = 3.8$ K. The metallurgical characterization by Laue x-ray scattering and powder x-ray diffraction shows the excellent crystalline quality, which is confirmed by very high residual-resistivity ratios (RRR). Magnetization, specific heat, torque magnetometry, resistivity, and Hall-effect measurements down to 50 mK and up to 18 T were carried out. The low-temperature measurements in the antiferromagnetic regime show complex magnetic behavior. The Hall-effect cannot be explained by a superposition of anomalous and normal Hall-effect.

TT 9.7 Tue 13:30 P

Robust hybridization gap in the Kondo insulator YbB_{12} probed by femtosecond optical spectroscopy — •Amrit raj Pokharel[1], Steinn y. Agustsson[1], Viktor v. Kabanov[2], Fumitoshi Iga[3], Toshiro Takabatake[4], Hidekazu Okamura[5], and Jure Demsar[1] — [1]JGU Mainz, Mainz, Germany — [2]Jozef Stefan Institute, Ljubljana, Slovenia — [3]Ibaraki University, Mito, Japan — [4]Hiroshima University, Higashi-Hiroshima, Japan — [5]Tokushima University, Tokushima, Japan

Carrier relaxation dynamics is susceptible to subtle changes in the low energy electronic structure. In heavy fermions the dynamics is shown to be governed by the low energy indirect gap, E_g, resulting from interplay/hybridization between localized moments and conduction band electrons. Here, carrier relaxation dynamics in a prototype Kondo insulator YbB_{12} is studied over large temperature range and over three orders of magnitude in excitation density. We utilize the intrinsic nonlinearity of dynamics to quantitatively determine microscopic parameters, such as electron-hole recombination rate. The extracted value reveals that hybridization is accompanied by a strong charge transfer from localized 4f levels. Furthermore, results suggest hybridization gap to be present up to temperatures of the order of $E_g/k_B \approx 200$ K, and is extremely robust against electronic excitation. Finally, the results imply further changes in the low energy electronic structure below 20 K, attributed to short-range antiferromagnetic correlations between the localized levels [1].

[1] A. R. Pokharel, et. al., Phys. Rev. B 103, 115134 (2021)

TT 9.8 Tue 13:30 P

Floquet renormalization group approach to the periodically driven Kondo model — •Valentin Bruch[1], Mikhail Pletyukhov[1], Herbert Schoeller[1], and Dante Kennes[1,2] — [1]Institute for Theory of Statistical Physics, RWTH Aachen, 52056 Aachen, Germany and JARA-FIT, 52056 Aachen — [2]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, 22761 Hamburg, Germany

We study the interplay of strong correlations and coherent driving by considering the Kondo model driven by a time-periodic bias voltage. By combining a recent nonequilibrium renormalization group method with Floquet theory, we find that the coherent dressing of the driving field leads to side-replicas of the Kondo resonance in the conductance, which are not completely washed out by the decoherence induced by the driving. We show that to accurately capture the interplay of driving and strong correlations one needs to go beyond simple phenomenological pictures, which underestimate decoherence, or adiabatic approximations, highlighting the relevance of memory effects. Within our method the differential conductance shows good quantitative agreement with experimental data in the full crossover regime from weak to strong driving. In the time-resolved current and differential conductance we identify nonlinear memory effects and time scales of the relaxation to the ground state.

TT 9.9 Tue 13:30 P

Quadrature Magnetoresistance from Impeded Cyclotron Motion — •Roemer Hinlopen[1], Stijn Hinlopen[2], Jake Ayres[1], and Nigel Hussey[1,3] — [1]University of Bristol, United Kingdom — [2]Fudura B.V., Netherlands — [3]High Field Magnet Laboratory (HFML-EMFL), Netherlands

Recently, quadratic to linear magnetoresistance (MR) as a function of magnetic field has emerged as a pervasive phenomenon among strange and quantum critical metals. Examples are the antiferromagnetic quantum critical metal $BaFe_2(As,P)_2$ (1), heavy fermion $(Yb,La)Rh_2Si_2$ (2) and optimally and overdoped cuprates (Nd-)LSCO (3,4), Tl-2201 and Bi-2201 (5) as well as electron doped LCCO (6). Given the variety of Fermi surface topologies, dominant interactions and energy scales in these systems, the striking similarity of their magnetic-field response suggests some universal, but as yet unidentified, organizing principle. Here, we propose a new, simple theory to explain this phenomenology based on impeded cyclotron motion. We reproduce the quadrature form and show a high level of robustness to scattering and correlation effects. The unsaturating nature of the MR is found even in the high field limit. We predict this model also explains the magnetoresistance observed in charge density wave systems such as the dichalcogenides.

[1] Nat. Phys. 12:916-919 (2016)
[2] Physica B: Cond. Matt. 378-380:72-73 (2006)
[3] Science 361:6401 (2018)
[4] G. Grissonnanche arXiv:2011.13054 (2020)
[5] J. Ayres et al. Nature (in press)
[6] Sci. Adv. 5:5, eaav6753 (2019)

TT 9.10 Tue 13:30 P

Possible superconductivity from incoherent carriers in overdoped cuprates — •Caitlin Duffy[1], Matija Čulo[1,2], Jake Ayres[1,3], Maarten Berben[1], Yu-Te Hsu[1], Roemer Hinlopen[3], Bence Bernáth[1], and Nigel Hussey[1,3] — [1]High Field Magnet Laboratory (HFML-EMFL), Netherlands — [2]Institut za fiziku, Zagreb, Croatia — [3]University of Bristol, United Kingdom

The non-superconducting normal state of the overdoped, hole-hoped cuprates is formed of two distinct charge sectors: one coherent with quasiparticle excitations, the other incoherent and governed by non-quasiparticle Planckian dissipation (1). From $p^* = 0.19$ to the end of the superconducting dome, a decrease in the superfluid carrier density $n_s(0)$ concurrent with an increase in the Hall (coherent) carrier density $n_{\mathrm{H}}(0)$ from p to $1+p$ is found; this striking anti-correlation contradicts the expectations of conventional BCS theory (2, 3). Here, we demonstrate that in two families of cuprates - $La_{2-x}Sr_xCuO_4$ and $Tl_2Ba_2CuO_{6+\delta}$ - the loss of carriers in the coherent sector is entirely compensated for by the growth in $n_s(0)$ with decreasing p. This implies that superconductivity in the overdoped cuprates stems from the sector that displays incoherent transport properties (4).

[1] J. Ayres *et al.*, *Nature*, (in press)
[2] I. Božović *et al.*, *Nature* **536**, 309*311 (2016)
[3] C. Putzke *et al.*, *Nat. Phys.* **17**, 826 (2021)
[4] M. Čulo, C. Duffy *et al.*, *SciPost Phys.* **11**, 012 (2021)

TT 9.11 Tue 13:30 P

Emergence of a fluctuating magnetic ground state in $Mn_{1-x}Fe_xSi$ — Andreas Bauer[1], Jonas Kindervater[1], •Johanna K. Jochum[2], Wolfgang Häussler[1,2], Nicolas Martin[3], Markus Garst[4], and Christian Pfleiderer[1] — [1]Physik Department, Technische Universität München, D-85748 Garching, Germany — [2]Heinz Maier-Leibnitz Zentrum, Technische Universität München, D85748 Garching, Germany — [3]Université Paris-Saclay, CNRS, CEA, Laboratoire Léon Brillouin, 91191 Gif-sur-Yvette, France — [4]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, D-76131 Karlsruhe, Germany

Substitutional doping of the cubic chiral magnet MnSi results in a suppression of magnetic order and quantum critical behavior that is masked by the influence of disorder. Combining measurements of the ac susceptibility and specific heat with elastic neutron scattering and neutron resonance spin-echo spectroscopy on single-crystal $Mn_{1-x}Fe_xSi$ in zero magnetic field, we show that up to $x = 0.10$ static helimagnetic order emerges through a Brazovskii-type fluctuation-induced first-order phasetransition. For $x = 0.12$, the signatures in the susceptibility are reminiscent of helimagnetic order, while the specific heat indicates the absence of a first-order transition and neutron spectroscopy unambiguously establishes the dynamic character down to temperatures of 50 mK, suggesting a magnetic ground state that is dominated by interacting chiral fluctuations.

TT 9.12 Tue 13:30 P

Orientation dependence of the transverse-field Ising transition in $LiHoF_4$ — •Andreas Wendl[1], Heike Eisenlohr[2], Felix Rucker[1], Christopher Duvinage[1], Markus Kleinhans[1], Matthias Vojta[2], and Christian Pfleiderer[1,3,4] — [1]Physik Department, TU München, Garching, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, Dresden, Germany — [3]Centre for QuantumEngineering (ZQE), TU München, Garching, Germany — [4]Munich Centre for Quantum Science and Technology (MCQST), TU München, Garching, Germany

The perhaps best understood example of a quantum critical point is the response of the dipolar Ising ferromagnet $LiHoF_4$ to a transverse field [1-3]. We report an investigation of the AC susceptibility of $LiHoF_4$ as a function of the magnetic field direction relative to the hard magnetic axis, deriving the evolution of the magnetic-phase-diagram as a function of field orientation. We discuss our findings in terms of a theoretical model taking quantiatively into account the non-Kramers nature of the Ho ions, the effects of hyperfine coupling and the presence of magnetic domains.

[1] D. Bitko et al., Phys. Rev. Lett. **77**, 940 (1996)
[2] H. M. Rønnow et al., Science **308**, 389 (2005)
[3] P. B. Chakraborty et al., Phys. Rev. B **70**, 144411 (2004)

TT 9.13 Tue 13:30 P

Pump-Probe AC Susceptibility of $LiHo_xY_{1-x}F_4$ (x = 4.5 %) — •Michael Lampl, Andreas Wendl, Markus Kleinhans, Laura Stapf, Marc A. Wilde, and Christian Pfleiderer — Physik-Department Technical University of Munich, Garching, Germany

$LiHoF_4$ under a transverse magnetic field exhibits one of the best understood examples of a quantum critical point. Substitutional doping of Ho with non-magnetic Yttrium may be used to study the effects of disorder [1]. In the highly diluted system $LiHo_xY_{1-x}F_4$ (x = 4.5 %), investigated in our study, the nature of the ground state is still unresolved [2]. To explore the ground state properties of this system, multiple studies employed so-called pump-probe susceptibility measurements [3-5]. We revisit this question and report a study of the pump-probe susceptibility as a function temperature and field orientation, covering a wide parameter range.

[1] J. P. Gingras and P. Henelius, J. Phys.: Conf. Ser. **320**, 012001 (2011).
[2] J. A. Quilliam *et al.*, Phys. Rev. Lett. **101**, 187204 (2008).
[3] S. Ghosh *et al.*, Science **296**, 2195 (2002)
[4] M. A. Schmidt *et al.*, Proc. Natl. Acad. Sci. USA **111**, 3689 (2014)
[5] D. M. Silevitch *et al.*, Nature Com. **10**, 4001 (2019)

TT 9.14 Tue 13:30 P

Gross-Neveu-Heisenberg criticality from competing nematic and antiferromagnetic orders in bilayer graphene — Shouryya Ray and •Lukas Janssen — TU Dresden, Germany

The nature of the ground state of Bernal-stacked bilayer graphene has received significant attention in the last ten years, but still represents an open problem both experimentally and theoretically. The two most promising scenarios feature nematic and antiferromagnetic orders. We have studied theoretically the competition between these two orders, revealing that they allow a coexistence phase characterized by both nematicity and antiferromagnetism. This leads to interesting quantum phase transitions, including weak first-order transitions and continuous Gross-Neveu-type transitions that feature emergent Lorentz invariance. Implications for experiments in bilayer graphene are discussed.

[1] S. Ray, L. Janssen, Phys. Rev. B 104, 045101 (2021)

TT 9.15 Tue 13:30 P

Terahertz conductivity of heavy-fermion systems from time-resolved spectroscopy — •Chia-Jung Yang[1], Shovon Pal[1], Farzaneh Zamani[2], Kristin Kliemt[3], Cornelius Krellner[3], Oliver Stockert[4], Hilbert v. Löhneysen[5], Johann Kroha[2], and Manfred Fiebig[1] — [1]ETH Zurich, Switzerland — [2]University of Bonn, Germany — [3]Goethe-University Frankfurt, Germany — [4]MPI CPfS Dresden, Germany — [5]KIT Karlsruhe, Germany

Ultrafast terahertz (THz) spectroscopy has recently been introduced as a novel tool to investigate the quasiparticle dynamics across the quantum phase transition in heavy-fermion compounds [1,2]. The incident THz pulse with a spectral range of 0.1–3 THz creates collective intraband excitations within the heavy band as well as resonant interband transitions between the hybridizing heavy and light parts of the conduction band. The former leaves the heavy quasiparticles intact, while the latter breaks the Kondo-singlet and leads to a time-delayed echo-like response [1,2]. In this contribution, we expand our investigations towards the individual transport properties of strongly and weakly correlated electrons. We utilize the time-resolved, phase-sensitive THz spectroscopy to separate two types of excitations and derive the associated optical conductivity. We find that the Kondo-singlet-breaking interband transitions do not create a conventional metallic Drude peak, while the Kondo-retaining intraband excitations yield the Drude response as expected [3].

[1] C. Wetli *et al.*, Nat. Phys. **14**, 1103 (2018)
[2] S. Pal *et al.*, PRL **122**, 096401 (2019)
[3] C.-J. Yang *et al.*, PRR **2**, 033296 (2020)

TT 9.16 Tue 13:30 P

Multifractality at the spin quantum Hall (class C) transition — •Martin Puschmann[1], Daniel Hernangómez-Pérez[2], Bruno Lang[3], Soumya Bera[4], and Ferdinand Evers[1] — [1]Institute of Theoretical Physics, University of Regensburg, D-93053 Regensburg, Germany — [2]Department of Molecular Chemistry and Material Science, Weizmann Institute of Science, Rehovot 7610001, Israel — [3]IMACM and Institute of Applied Computer Science, Bergische Universität Wuppertal, D-42119 Wuppertal, Germany — [4]Department of Physics, Indian Institute of Technology Bombay, Mumbai 400076, India

Recent analytical work on the integer quantum Hall transition (class A) predicts a parabolic dependency of the exponents τ_q, that describe the system-size scaling of wavefunction moments $|\psi|^{2q}$. [1] The prediction has raised attention, since it contradicts numerical observations [2]. The arguments of [1] rely on conformal invariance and therefore are believed to carry over also to class C. Since in class C corrections to scaling are under control, it provides an excellent laboratory for testing the salient concepts numerically. Thus motivated, we investigate τ_q in class C and eliminate subleading powers guided by finite-size corrections of distribution functions. Thereby, we demonstrate unambiguously the presence of quartic terms in τ_q [3], inconsistent with the predicted parabolic shape but in agreement with [4].

[1] M. R. Zirnbauer, Nucl. Phys. B 941, 458 (2019)
[2] e.g. K. Slevin and T. Ohtsuki, Phys. Rev. B 80, 041304 (2009)
[3] M. Puschmann et al., Phys. Rev. B 103, 235167 (2021)
[4] J. Karcher et al., arXiv:2107.06414

TT 9.17 Tue 13:30 P

Spin-phonon interaction and tunnel splitting in single-molecule magnets — •Kilian Irländer[1], Jürgen Schnack[1], and Heinz-Jürgen Schmidt[2] — [1]Fakultät für Physik, Universität Bielefeld, Postfach 100131, Bielefeld D-33501, Germany — [2]Fachbereich Physik, Universität Osnabrück, Osnabrück D-49069, Germany

Quantum tunneling of the magnetization is a phenomenon that impedes the use of small anisotropic spin systems for storage purposes even at the lowest temperatures. Phonons, usually considered for temperature dependent relaxation of magnetization over the anisotropy barrier, also contribute to magnetization tunneling for integer spin quantum numbers. In this context, it is not viable to consider phonons perturbatively but to treat spins and phonons on the same footing by performing quantum calculations of a Hamiltonian where the single-ion anisotropy tensors are coupled to harmonic oscillators. We demonstrate the ability of phonons to induce a tunnel splitting of the ground doublet which then reduces the required bistability due to Landau-Zener tunneling of the magnetization [Phys. Rev. B 102, 054407]. We also present the unexpected observation that certain spin-phonon Hamiltonians are robust against the opening of a tunneling gap, even for strong spin-phonon coupling. The key to understanding this phenomenon is provided by an underlying supersymmetry that involves both spin and phonon degrees of freedom.

[1] Eur. Phys. J. B 94, 68

TT 9.18 Tue 13:30 P

NMR investigations of the 2D Heisenberg system CuPOF under pressure — •F. Bärtl[1,2], D. Opherden[1,2], C. P. Landee[3], S. Molatta[1,2], J. Wosnitza[1,2], M. Baenitz[4], and H. Kühne[1] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Department of Physics, Clark University, Worcester, Massachusetts, USA — [4]MPI for Chemical Physics of Solids, Dresden, Germany

The molecular-based material CuPOF ($[Cu(pz)_2(2\text{-}OHpy)_2](PF_6)_2$) is an excellent realization of a two-dimensional square-lattice quantum $S = 1/2$ Heisenberg antiferromagnet, with an intralayer exchange coupling $J/k_B = 6.8$ K and an interlayer coupling $J' \approx 10^{-4}J$. Previously reported nuclear magnetic resonance (NMR) data revealed a low-temperature transition to commensurate antiferromagnetic (AF) quasistatic long-range order (LRO), with a preceding crossover from isotropic Heisenberg to anisotropic XY behaviour. We present further NMR studies of the low-temperature correlations in magnetic fields up to 7 T and temperatures down to 0.3 K. The application of hydrostatic pressure up to 10 kbar leads to a change of the interlayer coupling and, therefore, the magnetic correlations in the critical regime. The transition regime is probed by ^{1}H and ^{31}P spectroscopy and relaxometry, revealing a non-monotonic change of T_N with increasing pressure. The commensurate AF LRO below T_N still persists at high pressures, as revealed by a splitting of the ^{1}H NMR lines, stemming from the broken symmetry of the local spin polarizations in the LRO regime.

TT 9.19 Tue 13:30 P

Magnetic heat transport and strong magneto-elastic coupling in the frustrated spin-chain mineral linarite — •Matthias Gillig[1,2], Xiaochen Hong[1,3], Piyush Sakrikar[4], Gaël Bastien[5], Anja Wolter[1], Leonie Heinze[6], Satoshi Nishimoto[1,2], Bernd Büchner[1,2], and Christian Hess[1,3] — [1]IFW Dresden, Germany — [2]TU Dresden, Germany — [3]Bergische Universität Wuppertal, Germany — [4]IISER Mohali, India — [5]Charles University, Prague, Czech Republic — [6]TU Braunschweig, Germany

Motivated by recent theoretical results predicting a finite thermal Drude weight in frustrated spin chains, we have studied the thermal conductivity of the mineral Linarite $PbCuSO_4(OH)_2$ at low temperature. In this well-studied material the Cu-ions form a s=1/2 spin chain with competing FM nearest-neighbor and AFM next-nearest-neighbor interactions, creating a magnetically frustrated system which orders below $T_N = 2.8$ K in an elliptical spiral ground state. In a magnetic field along the spin chain, other magnetically ordered phases can be induced. Our results reveal that the thermal conductivity κ in zero field is dominated by a phononic contribution. As a function of magnetic field κ shows a peculiar non-monotonic behavior. Whenever the magnetic field value approaches a critical field, κ is highly suppressed. This trend can be explained by magnetic fluctuations which are expected near a phase boundary and which reduce thermal conductivity due to strong phonon scattering. Furthermore, a magnon thermal transport channel was verified in the spiral phase.

TT 9.20 Tue 13:30 P

Vibrating-coil magnetometry of the magnetic phase diagram of $Gd_2Ga_5O_{12}$ — •Markus Kleinhans and Christian Pfleiderer — Physik-Department, Technische Universität München, D-85748 Garching, Germany

Magnetic frustration attracts great interest since it leads to exotic magnetic orders like spin liquids, spin glasses and spin ice all associated with the geometric frustration of magnetic spins. We report vibrating coil magnetometry down to mK temperatures [2] of the frustrated system $Gd_2Ga_5O_{12}$[1,3,4]. Based on the magnetization measured in a spherical sample for field along ⟨100⟩, ⟨110⟩, and ⟨111⟩ we track the magnetic phase diagram as a function of field orientation in great detail.

[1] P. P. Deen textitet al., PRB **91**, 014419 (2015)
[2] S. Legl *et al.*, RSI **81**, 043911 (2010)
[3] S. Hov. *et al.*, JMMM **455-456**, 15-18 (1980)
[4] P. Schiffer and A.P. Ramirez *et al.*, PRL **2500**, 73 (1994)

TT 9.21 Tue 13:30 P

Low-temperature investigation of thermodynamic properties on the spin-liquid candidate system $PbCuTe_2O_6$ in various finite fields. — •Paul Eibisch[1], Christian Thurn[1], Ulrich Tutsch[1], Arif Ata[1], Abanoub R. N. Hanna[2,3], A. T. M. Nazmul Islam[3], Shravani Chillal[3], Bella Lake[3], Bernd Wolf[1], and Michael Lang[1] — [1]PI Goethe-University Frankfurt — [2]IFKP, TU Berlin — [3]HZ Berlin

The quantum spin liquid is an exotic state of magnetic systems which shows no long-range order down to $T = 0$ K but instead exhibits persistent spin dynamics with highly entangled spins fluctuating between various degenerate configurations. A favourable route to realize this state is to use geometric frustrations for instance in 2D materials where the spins interact on top of a kagome lattice. In this study we present low-temperature thermodynamic measurements in various fields on the spin-liquid candidate system $PbCuTe_2O_6$ showing a Hyper-kagome lattice, a 3D adaptation of the 2D kagome lattice. First investigations on polycrystalline samples supported the spin-liquid character [1], whereas more recent studies revealed an even more exotic behaviour i.e. a ferroelectric phase transition around $T = 1$ K together with a diverging thermal Grüneisen parameter, indicating proximity to a quantum critical point [2]. Here we show that the magnetic Grüneisen parameter diverges as well, supporting zero-field-quantum-critical behaviour. Further focus of our investigations lies on the field dependence of the ferroelectric transition.

[1] S.Chillal *et al.*, Nat. Commun. **11**, 2348 (2020)
[2] C.Thrun *et al.*, arXiv:2103.17175

TT 9.22 Tue 13:30 P

Nesting instability of gapless U(1) spin liquids with spinon Fermi pockets in two dimensions — •Wilhelm Krüger and Lukas Janssen — TU Dresden, 01062 Dresden, Germany

Quantum spin liquids are exotic states of matter that may be realized in frustrated quantum magnets and feature fractionalized excitations and emergent gauge fields. Here, we consider a gapless U(1) spin liquid with spinon Fermi pockets in two spatial dimensions. Such a state appears to be the most promising candidate to describe the exotic field-induced behavior observed in numerical simulations of the antiferromagnetic Kitaev honeycomb model. A similar such state may also be responsible for the recently-reported quantum oscillations of the thermal conductivity in the field-induced quantum paramagnetic phase of α-$RuCl_3$. We consider the regime close to a Lifshitz transition, at which the spinon Fermi pockets shrink to small circles around high-symmetry points in the Brillouin zone. By employing renormalization group and mean-field arguments, we demonstrate that interactions lead to a gap opening in the spinon spectrum at low temperatures, which can be understood as a nesting instability of the spinon Fermi surface. This leads to proliferation of monopole operators of the emergent U(1) gauge field and confinement of spinons. While signatures of fractionalization may be observable at finite temperatures, the gapless U(1) spin liquid state with nested spinon Fermi pockets is ultimately unstable at low temperatures towards a conventional long-range-ordered ground state, such as a valence bond solid. Implications for Kitaev materials in external magnetic fields are discussed.

TT 9.23 Tue 13:30 P

Magnetostriction in the J-K-Γ-model on the honeycomb lattice — •Alexander Schwenke and Wolfram Brenig — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany

Using the numerical linked cluster expansion (NLCE) [1], we investigate thermodynamic and magnetoelastic properties of the J-K-Γ spin-$\frac{1}{2}$ model on the honeycomb lattice in the presence of a magnetic field $\vec{B}$, for field orientations both in-plane and out-of-plane.

Apart from the specific heat and the magnetization, we focus in particular on the linear magnetostriction coefficient $\lambda(B,T)$. As a prime result and based on expansions up to order $\sim \mathcal{O}(11)$, we find clear indications for a field-induced transition in $\lambda(B,T)$.

Employing exchange parameters as proposed for $\alpha - RuCl_3$, our results are very similar to recently observed experimental data [2] on this proximate quantum spin-liquid candidate material.

[1] M. Rigol et al., Phys. Rev. Lett. 97, 187202 (2006)
[2] S. Gass et al., Phys. Rev. B 101, 245158 (2020)

TT 9.24 Tue 13:30 P

Glass-like transitions in the frustrated charge system θ-$(BEDT\text{-}TTF)_2CsM(SCN)_4$ (M = Cs and Co) revealed by thermal expansion measurements — •Yohei Saito[1], Tatjana Thomas[1], Steffi Hartmann[1], Tim Thyzel[1], Yassine Agarmani[1], Hungwei Sun[1], Jens Müller[1], Kenichiro Hashimoto[2], Takahiko Sasaki[2], Hiroshi Yamamoto[3], and Michael Lang[1] — [1]Institute of Physics, Goethe University Frankfurt, Frankfurt (M), Germany — [2]Institute for Materials Research, Tohoku University, Sendai, Japan — [3]Institute for Molecular Science, Okazaki, Japan

Geometrical frustration causes degenerate states, giving rise to intriguing quantum phenomena such as a spin liquid. In addition to a frustrated spin system, a frustrated charge system is proposed in organic conductors called θ-type BEDT-TTF salts. It is expected that charge ordering is suppressed and is possibly replaced by a charge glass state. In organic charge-ordered salts, the charge order transition accompanies a structural transition. Therefore, investigating their elastic properties is of fundamental interest. We performed thermal expansion measurements on θ-(BEDT-TTF)$_2$CsM(SCN)$_4$ (M = Cs and Co) that does not show charge ordering. The thermal expansion coefficient exhibited a glassy transition at 90-100 K. This behavior is reminiscent of the freezing of the terminal ethylene end-groups on the BEDT-TTF molecules. We also found another glassy transition at 120-130 K for both salts where the development of a superlattice structure was reported. These results point to the importance of the lattice degrees of freedom in the frustrated charge system.

TT 9.25 Tue 13:30 P

The one-dimensional Long-Range Falikov-Kimball Model: Thermal Phase Transition and Disorder-Free Localisation — •Thomas Hodson[1], Josef Willsher[2], and Johannes Knolle[2,3,1] — [1]Blackett Laboratory, Imperial College London, London SW72AZ, United Kingdom — [2]Department of Physics TQM, Technische Universit at Munchen,James-Franck-Strasse 1, D-85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Disorder or interactions can turn metals into insulators. One of the simplest settings to study this physics is given by the FK model, which describes itinerant fermions interacting with a classical Ising background field. Despite the translational invariance of the model, inhomogenous configurations of the background field give rise to effective disorder physics which lead to a rich phase diagram in two (or more) dimensions with finite temperature charge density wave (CDW) transitions and interaction-tuned Anderson versus Mott localized phases. Here, we propose a generalised FK model in one dimension with long-range interactions which shows a similarly rich phase diagram. We use an exact Markov Chain Monte Carlo method to map the phase diagram and compute the energy resolved localisation properties of the fermions. We compare the behaviour of this transitionally invariant model to an Anderson model of uncorrelated binary disorder about a background CDW field which confirms that the fermionic sector only fully localizes for very large system sizes.

TT 9.26 Tue 13:30 P

Anisotropic Magnetoresistance in LAO/STO nanostructures — •Mithun S Prasad[1] and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Von-Danckelmann-Platz 3, D-06120 Halle, Germany — [2]Interdisziplinäres Zentrum für Meterialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Heinrich-Damerow-Straße 4, D-06120 Halle, Germany

The high-mobility two-dimensional electron gas (2DEG) confined at the interface LaAlO3 (LAO) and SrTiO3 (STO) provides new opportunities to explore Nanoelectronic devices. In our group, we have developed an industry-compatible Nanopatterning technique [1] for the LAO/STO interface. Recent studies on this interface have revealed that at low temperature the current is confined to filaments which are linked to structural domain walls in the STO[2] with drastic consequences for example for the temperature dependence of local transport properties [3]. We have investigated magneto-transport in nanostructures having a different crystalline orientation with respect to the lattice. Our experiments show that not only the resistance but also the magnetoresistance varies with orientation. The magnetoresistance can even change sign strongly supporting the model of filamentary charge transport. The angle of orientation of the domain walls can lead to various localization effects on the application of magnetic fields which can explain the anisotropy found in our experiments.

[1] M. Z. Minhas et.al, AIP Advances 6, 035002 (2016)
[2] Kalisky et.al, Nat. Mat. 12, 1091-1095 (2013)
[3] M. Z. Minhas et.al, Sci. Rep. 7, 5215(2017)

TT 9.27 Tue 13:30 P

Anisotropic metamagnetism in trilayer ruthenate $Sr_4Ru_3O_{10}$ — •Izidor Benedičič[1], Masahiro Naritsuka[1], Luke C. Rhodes[1], Rosalba Fittipaldi[2], Veronica Granata[3], Christopher Trainer[1], Antonio Vecchione[2], and Peter Wahl[1] — [1]School of Physics and Astronomy, University of St Andrews, North Haugh. St Andrews, Fife KY16 9SS, United Kingdom — [2]CNR-SPIN, UOS Salerno, Via Giovanni Paolo II 132, I-84084, Fisciano, Italy — [3]Dipartimento di Fisica "E.R.Caianiello", Universita di Salerno, I-84084 Fisciano, Salerno,Italy

The ground state of metamagnetic materials can be precisely controlled by application of magnetic field, making them exciting candidates for spintronic applications. In itinerant metamagnets, such as trilayer ruthenate $Sr_4Ru_3O_{10}$, understanding their electronic structure is crucial for successful manipulation and tuning of their magnetic properties. I will show measurements using quasiparticle interference imaging in a low temperature scanning tunneling microscope to study the electronic structure of $Sr_4Ru_3O_{10}$ in magnetic field. We find a strongly anisotropic response to the in-plane field, suggesting an unusually strong effect of the orthorhombic distortion on the electronic structure. Using DFT calculations, we can model the QPI signal and find the Fermi surface dominated by bands of spin-minority character, putting constraints on theories for the origin of the metamagnetic transition.

TT 9.28 Tue 13:30 P

Real-space cluster dynamical mean-field theory: Center focused extrapolation on the one- and two particle level — Marcel Klett[1], •Nils Wentzell[2], Thomas Schaefer[1], Fedor Simkovic[3], Olivier Parcollet[2], Sabine Andergassen[4], and Philipp Hansmann[5] — [1]Theory of strongly correlated quantum matter, Max Planck Institute for Solid State Research, Stuttgart — [2]Center for Computational Quantum Physics, Flatiron institute, NYC — [3]College de France, Paris — [4]Institut fuer Theoretische Physik and Center for Quantum Science, University Tuebingen — [5]Institut für Theoretische Physik, Friedrich-Alexander-University Erlangen-Nuernberg

We revisit the cellular dynamical mean-field theory (CDMFT) for the single band Hubbard model on the square lattice at half filling, reaching real-space cluster sizes of up to 9 x 9 sites. Using benchmarks against direct lattice diagrammatic Monte Carlo at high temperature, we show that the self-energy obtained from a cluster center focused extrapolation converges faster with the cluster size than the periodization schemes previously introduced in the literature. The same benchmark also shows that the cluster spin susceptibility can be extrapolated to the exact result at large cluster size, even though its spatial extension is larger than the cluster size.

We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG) through ZUK 63 and Project No. AN 815/6-1

TT 9.29 Tue 13:30 P

Spectral function of the Hubbard model using cluster perturbation theory — •Nicklas Enenkel[1], Peter Schmitteckert[2], and Markus Garst[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Deutschland — [2]HQS - Quantum Simulations, Karlsruhe, Deutschland

The spectral function of the single band Hubbard model is calculated as part of a benchmark study using cluster perturbation theory (CPT). Within the framework of CPT, the Green function of a certain cluster of sites is first calculated numerically exactly, and, in a second step, the hopping of electrons between the clusters is treated in perturbation theory. Practically, however, a numerically reliable determination of the cluster Green function poses a challenge, and we compare various numerical approaches involving exact diagonalization, Chebychev expansion and equation of motion techniques. Results for the full spectral function are presented and discussed for the one- and two-dimensional Hubbard model.

TT 9.30 Tue 13:30 P

Four-point functions on the real-frequency axis – A spectral representation and its numerical evaluation — •Fabian B. Kugler[1,2], Seung-Sup B. Lee[2], and Jan von Delft[2] — [1]Rutgers University, USA — [2]LMU Munich, Germany

We present spectral representations for multipoint correlation functions for each of three widely-used formalisms: the imaginary-frequency Matsubara formalism and the real-frequency zero-temperature as well as Keldysh formalisms. The spectral representations separate information on the system's dynamics, encoded in universal partial spectral functions, from the correlators' analytical properties, encoded in formalism-dependent convolution kernels [1]. We present numerical results for the four-point vertex of the Anderson impurity model, obtained by a novel numerical renormalization group scheme [2]. In the imaginary-frequency Matsubara formalism, our approach allows us to compute the vertex at arbitrarily low temperatures and to follow the complete crossover from strongly interacting particles to weakly interacting quasiparticles. In the real-frequency Keldysh formalism, we first benchmark our method against analytical results at weak and infinitely strong interaction. Then, we consider the dynamical mean-field solution of the Hubbard model to reveal the rich real-frequency structure of the vertex in the metal-insulator coexistence regime.

[1] F. B. Kugler, S.-S. B. Lee, J. von Delft, arXiv:2101.00707, accepted in PRX
[2] S.-S. B. Lee, F. B. Kugler, J. von Delft, arXiv:2101.00708, accepted in PRX

TT 9.31 Tue 13:30 P

Accuracy of the typicality approach using Chebyshev polynomials — Florian Gayk[1], Heinz-Jürgen Schmidt[2], Andreas Honecker[3], Jürgen Schnack[4], and •Henrik Schlüter[4] — [1]Fakultät für Physik, Universität Bielefeld, Postfach 100131, Bielefeld D-33501, Germany — [2]Fachbereich Physik, Universität Osnabrück, Osnabrück D-49069, Germany — [3]Laboratoire de Physique Théorique et Modélisation, CNRS UMR 8089, CY Cergy Paris Université, Cergy-Pontoise Cedex F-95302 — [4]Fakultät für Physik, Universität Bielefeld, Postfach 100131, Bielefeld D-33501, Germany

Trace estimators allow us to approximate thermodynamic equilibrium observables with astonishing accuracy. A prominent representative is the finite-temperature Lanczos method (FTLM) which relies on a Krylov space expansion of the exponential describing the Boltzmann weights. Here we report investigations of an alternative approach which employs Chebyshev polynomials [1]. This method turns out to be also very accurate in general, but shows systematic inaccuracies at low temper- atures that can be traced back to an improper behaviour of the approximated density of states with and without smoothing kernel. Applications to archetypical quantum spin systems are discussed as examples.

[1] H. Schlüter, F. Gayk, H.-J. Schmidt, A. Honecker and J. Schnack, Zeitschrift für Naturforschung A, 2021 https://doi.org/10.1515/zna-2021-0116

TT 9.32 Tue 13:30 P

Inhomogeneous mean-field approach to collective excitations near the superfluid–Mott glass transition — •Martin Puschmann[1,2], João C. Getelina[1,3], José A. Hoyos[3], and Thomas Vojta[1] — [1]Department of Physics, Missouri University of Science and Technology, Rolla, Missouri, 65409, USA — [2]Institute of Theoretical Physics, University of Regensburg, D-93040, Regensburg, Germany — [3]Instituto de Física de São Carlos, Universidade de São Paulo, C.P. 369, São Carlos, São Paulo, 13560-970, Brazil

We develop an inhomogeneous quantum mean-field approach to the behavior of collective excitations across the superfluid–Mott glass transition in two dimensions, complementing recent quantum Monte Carlo simulations [1,2]. In quadratic approximation, the Goldstone (phase) and Higgs (amplitude) modes completely decouple. Each is described by a disordered Bogoliubov Hamiltonian which can be solved by an inhomogeneous multi-mode Bogoliubov transformation. We find that the Higgs mode is spatially localized in both phases. The corresponding scalar spectral function shows a broad peak that is noncritical in the sense that its peak frequency does not soften but remains nonzero across the quantum phase transition. In contrast, the lowest-energy Goldstone mode delocalizes in the superfluid phase, leading to a zero-frequency spectral peak. We compare these findings to both the results of the quantum Monte Carlo simulations and the general knowledge on localization of bosonic excitations. We also show first results for three-dimensional systems.

[1] M. Puschmann et al., Phys. Rev. Lett. 125 (2020), 027002
[2] M. Puschmann et al., Ann. Phys. (2021), 168526

TT 9.33 Tue 13:30 P

Applications of real-space truncated unity functional RG — •Jonas B. Hauck[1], Carsten Honerkamp[2], and Dante M. Kennes[1,3] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen, 52074 Aachen,Germany and JARA - Fundamentals of Future Information Technology — [2]Institute for Theoretical Solid State Physics, RWTH Aachen University, 52074 Aachen, Germany and JARA - Fundamentals of Future Information Technology — [3]Max Planck Institute for the Structure and Dynamics of Matter and Center for Free Electron Laser Science, 22761 Hamburg, Germany

The discovery of superconductivity in a quasicrystalline material and its approximants lead to a plethora of theoretical predictions. Calculations in such systems are however computationally very heavy, rendering numerical verification of these hypotheses difficult. To resolve this issue we developed a real-space version of the truncated unity functional renormalization group. In this talk I will present this method and discuss its possible use when combining it with the momentum space TUfRG. I will give a short introduction into the derivation, the implementation and showcase the predictive power of the method by presenting our investigation of a penrose quasicrystal and the chiral edge modes in a $d + id$ superconductor.

TT 9.34 Tue 13:30 P

Tracking the footprints of spin fluctuations: a multi-method, multi-messenger study of the two-dimensional Hubbard model — •T. Schäfer[1], N. Wentzell[2], F. Šimkovic[3,4], Y.-Y. He[2], C. Hille[5], M. Klett[1], C. Eckhardt[6], B. Arzhang[7], V. Harkov[8], F.-M. Le Régent[4], A. Kirsch[4], Y. Wang[9], A. J. Kim[10], E. Kozik[10], E. A. Stepanov[8], A. Kauch[6], S. Andergassen[5], P. Hansmann[11], D. Rohe[12], Y. Vilk[9], J. P. F. LeBlanc[7], S. Zhang[2], A.-M. S. Tremblay[9], M. Ferrero[3,4], O. Parcollet[2], and A. Georges[2,3,4] — [1]MPI-FKF, Stuttgart — [2]CCQ, Flatiron Institute, New York — [3]Collège de France, Paris — [4]École Polytechnique, Palaiseau — [5]Universität Tübingen — [6]TU Wien — [7]Memorial University of Newfoundland — [8]University of Hamburg — [9]Université de Sherbrooke — [10]King's College London — [11]University of Erlangen-Nuremberg — [12]Forschungszentrum Juelich GmbH

This work represents an extensive multi-method, multi-messenger assessment of the wealth of computational methods that have been developed in recent years to determine the physical properties of the Hubbard model, the most fundamental model for electronic correlations, in two spatial dimensions. These methods range from simple mean-field theory to cutting-edge quantum-field theoretical approaches as dynamical mean field theory and its extensions. Each of these methods is compared to two numerically exact benchmarks and the role of magnetic fluctuations as well as their implications on the theory of metallic materials with strong magnetic correlations are elucidated.

TT 9.35 Tue 13:30 P

Enhancement of paring in asymmetric Hubbard ladder model — •Anas Abdelwahab, Gökmen Polat, and Eric Jeckelmann — Leibniz Universität Hannover, Hannover, Germany

We investigate a ladder system with two inequivalent legs, namely two legs with two different Hubbard interaction and two different intra-leg hopping terms. We use exact diagonalization and the density matrix renormalization group method to determine ground-state properties of this system at half-filling and at various doping. We found strong enhancement of pairing correlations of dopped ladders at some ranges of model parameters. We discuss the behaviors of charge, spin and pairing correlations.

TT 9.36 Tue 13:30 P

Orientational order parameters for arbitrary quantum systems* — •Michael te Vrugt and Raphael Wittkowski — Institut für Theoretische Physik, Center for Soft Nanoscience, Westfälische Wilhelms-Universität Münster, D-48149 Münster, Germany

The concept of quantum-mechanical nematic order, which is important in systems such as superconductors, is based on an analogy to classical liquid crystals, where order parameters are obtained through orientational expansions [1]. We generalize this method to quantum mechanics based on an expansion of Wigner functions [2]. This provides a systematic framework for the derivation of quantum order parameters, which unifies all known types of quantum orientational order into one framework and has a natural connection to the classical case. The formalism recovers the standard definitions for spin systems. For Fermi liquids, the formalism reveals the nonequivalence of various definitions of the order parameter used in the literature.

Funded by the Deutsche Forschungsgemeinschaft (DFG) - WI 4170/3-1

[1] M. te Vrugt, R. Wittkowski, AIP Adv. 10, 035106 (2020)
[2] M. te Vrugt, R. Wittkowski, Ann. Phys. (Berl.) 532, 2000266 (2020)

TT 9.37 Tue 13:30 P

Electronic transport in molecular junctions: The generalized Kadanoff-Baym ansatz with initial contact and correlations — •Riku Tuovinen[1], Robert van Leeuwen[2], Enrico Perfetto[3], and Gianluca Stefanucci[3] — [1]University of Helsinki, Finland — [2]University of Jyväskylä, Finland — [3]Università di Roma Tor Vergata, Italy

The generalized Kadanoff-Baym ansatz (GKBA) offers a computationally inexpensive approach to simulate out-of-equilibrium quantum systems within the framework of nonequilibrium Green's functions. For finite systems, the limitation of neglecting initial correlations in the conventional GKBA approach has recently been overcome [1]. However, in the context of quantum transport, the contacted nature of the initial state, i.e., a junction connected to bulk leads, requires a further extension of the GKBA approach. In this work, we lay down a GKBA scheme that includes initial correlations in a partition-free setting [2]. In practice, this means that the equilibration of the initially correlated and contacted molecular junction can be separated from the real-time evolution. The information about the contacted initial state is included in the out-of-equilibrium calculation via explicit evaluation of the memory integral for the embedding self-energy, which can be performed without affecting the computational scaling with the simulation time and system size. We demonstrate the developed method in carbon-based molecular junctions.

[1] D. Karlsson et al., Phys. Rev. B 98, 115148 (2018)
[2] R. Tuovinen et al., J. Chem. Phys. 154, 094104 (2021)

TT 9.38 Tue 13:30 P

Luttinger liquids with inhomogeneous interactions — Sebastian Huber[1] and •Marcus Kollar[2] — [1]Theoretical Solid State Physics, Ludwig-Maximilians-University, Munich, Germany; current address: Institute for Solid-State Physics, TU Wien, Austria — [2]Theoretical Physics III, University of Augsburg, Germany

We study a generalization of the two-flavor spinless Tomonaga-Luttinger model which includes inhomogeneous local interactions and scattering potentials [1]. For a wide range of parameters we obtain the spectrum and Green function exactly using Kronig identities with momentum transfer. While Green functions have a power-law form as in homogeneous Luttinger liquids, a sufficiently strong position dependence of the interaction breaks their translational invariance. Furthermore, the Luttinger-liquid interrelations between excitation velocities and Green function exponents are modified in such Luttinger droplets.

[1] S. Huber, M. Kollar, Phys. Rev. Research 2, 043336 (2020)

TT 9.39 Tue 13:30 P

RPA as exact high-density limit of 1D correlated electrons — •Klaus Morawetz[1,2], Vinod Ashokan[3], Renu Bala[4], and Kare Narain Pathak[5] — [1]Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — [2]International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil — [3]Department of Physics, Dr. B.R. Ambedkar NationalInstitute of Technology, Jalandhar (Punjab) - 144 011, India — [4]Centre for Advanced Study in Physics, Panjab University, 160014 Chandigarh, India — [5]Department of Physics, MCM DAV College for Women, 160036 Chandigarh, India

It is shown that in d-dimensional systems, the vertex corrections beyond the random phase approximation (RPA) or GW approximation scales with the power $d-\beta-\alpha$ of the Fermi momentum if the relation between Fermi energy and Fermi momentum is $\epsilon_f \sim p_f^\beta$ and the interacting potential possesses a momentum-power-law of $\sim p^{-\alpha}$. The condition $d<\beta+\alpha$ specifies systems where RPA is exact in the high-density limit. The one-dimensional structure factor is calculated analytically and the ground-state energy is presented exactly in the high-density and Coulomb limit. The proposed high-density expansion agrees with diffusive Monte Carlo simulations which we performed for this purpose.

[1] Eur. Phys. J. B 91 (2018) 29
[2] Phys. Rev. B 97 (2018) 155147
[3] Phys. Rev. B 101 (2020) 075130

TT 9.40 Tue 13:30 P

Quantum friction in the hydrodynamic model — •Kunmin Wu, Thomas Schmidt, and María Farias — Campus Limpertsberg, University of Luxembourg Faculty of Science, Technology and Medicine 162 A, avenue de la Faïencerie L-1511 Luxembourg

We study the phenomenon of quantum friction in a system consisting of a polarizable atom moving at a constant speed parallel to a metallic plate. The plate is described using a charged hydrodynamic model for the electrons. This model featuring long-range, instantaneous interactions is appropriate for graphene or a clean metal in a temperature range where scattering due to Coulomb interactions dominates over the scattering of electron by impurities. We find that a quantum friction force between the atom and the metal surface exists even in the absence of intrinsic damping in the plate, but that it only starts once the velocity of the atom exceeds the effective speed of sound in the plate. We argue that this condition can be fulfilled most easily in metals with nearly empty or nearly filled bands. We make quantitative predictions for the friction force to the second and fourth order in the atomic polarizability, and show that the threshold behavior persists to all orders of the perturbation theory.

TT 9.41 Tue 13:30 P

Dicke transition in open many-body systems determined by fluctuation effects — •Alla Bezvershenko[1], Catalin-Mihai Halati[2], Ameneh Sheikhan[2], Corinna Kollath[2], and Achim Rosch[1] — [1]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany — [2]Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We develop an approach to describe the Dicke transition of interacting many-particle systems strongly coupled to the light of a lossy cavity. A mean-field approach is combined with a perturbative treatment of fluctuations beyond mean-field, which becomes exact in the thermodynamic limit. Fluctuations are crucial to determine the mixed state character of the transition and to unravel universal properties of the emerging self-organized states. A rate equation is used to calculate an effective temperature. We validate our results by comparing to time-dependent matrix-product-state calculations.

TT 9.42 Tue 13:30 P

Dynamical quantum phase transitions in a chiral p-wave superconductor upon chemical potential quenches — •Yuto Shibata[1,2], Chitra Ramasubramanian[2], and Aline Ramires[1] — [1]Condensed Matter Theory Group, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland — [2]Institute for Theoretical Physics, ETH Zürich, 8093 Zürich, Switzerland

Dynamical quantum phase transitions (DQPTs) have been shown useful to identify non-trivial topology of quantum systems [1,2]. However, most of the preceding works do not incorporate self-consistency conditions for order parameters, which leads to periodic DQPTs.

Here, we study the dynamics of a two-dimensional chiral p-wave superconductor upon a quantum quench in the sign of the chemical potential within the BCS weak-coupling limit. We solve the BdG equations using fourth-order Runge-Kutta methods self-consistently and observe the phase of order parameter persistently oscillates sinusoidally in time after the quench. Despite the imposition of self-consistent conditions, periodic DQPTs are observed. These are identified as cusps in Loschmidt echo and accompanied by simultaneous creation of topological defects in the Pancharatnam geometric phase over curves in momentum space. We also discuss the robustness of the persistent phase oscillation against deformation of the Fermi surface and introduction of asymmetry to the chemical potential quenches.

[1] M. Heyl, Rep. Prog. Phys. **81**, 054001 (2018).
[2] N. Fläschner *et al.*, Nature Physics **14**, 265-268 (2018).

TT 9.43 Tue 13:30 P

Localization dynamics in a centrally coupled system — •Sebastian Wenderoth[1], Nathan Ng[2], Michael Kolodrubetz[3], Eran Rabani[2], and Michael Thoss[1] — [1]University of Freiburg, Freiburg, Germany — [2]University of California, Berkeley, USA — [3]University of Texas, Dallas, USA

In recent years, locally interacting system with static disorder, such as e.g. a random-field Ising chain with nearest neighbor interactions, received much attention because they can exhibit many-body localization. Many-body localized systems fail to equilibrate locally under unitary time evolution due to the absence of transport and the emergence of quasi-local integrals of motions, and thus, retain information about the initial state in local observables.

In our work, we explore the dynamics of a spin chain with a local antiferromagnetic interaction, and non-local spin-flip interactions induced by coupling of the spins to a central d-level system (qudit). We employ the multilayer multiconfiguration time-dependent Hartree approach [2,3] to simulate the dynamics of moderately large spin chains in a numerically exact way. Using this approach, we examine dynamical properties of the spin chain and the qudit, with particular focus on the question whether the system retains information about the initial state in local observables.

[1] A. Pal *et al.*, Phys. Rev. B **82**, 174411 (2010)
[2] H. Wang *et al.*, J. Chem. Phys. **119**, 1289 (2003)
[3] O. Vendrell *et al.*, J. Chem. Phys. **134**, 044135 (2011)

TT 10: Materials and devices for quantum technology (joint session HL/TT)

Time: Wednesday 10:00–12:45 Location: H4

Invited Talk TT 10.1 Wed 10:00 H4

Quantum Interference of Identical Photons from Remote Quantum Dots — •Giang N. Nguyen[1], Liang Zhai[1], Clemens Spinnler[1], Julian Ritzmann[2], Matthias C. Löbl[1], Andreas D. Wieck[2], Arne Ludwig[2], Alisa Javadi[1], and Richard J. Warburton[1] — [1]Department of Physics, University of Basel, Switzerland — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr- Universität Bochum, Germany

Photonic quantum technology provides a viable route to quantum communication, quantum simulation, and quantum information processing. Scaling the complexity requires photonic architectures containing a large number of single photons, multiple photon-sources and photon-counters. Semiconductor quantum dots are bright and fast sources of coherent single-photons. For applications, a significant roadblock is the poor quantum coherence upon interfering single photons created by independent quantum dots.

Here, we present two-photon interference with near-unity visibility using photons from remote quantum dots. We show a Hong-Ou-Mandel visibility of 93% between photons from quantum dots separated in two cryostats. Exploiting the quantum interference, we demonstrate a photonic controlled-not circuit and a high-fidelity entanglement between photons of different origins. These results provide a long-awaited solution to the challenge of creating coherent single photons in a scalable way.

TT 10.2 Wed 10:30 H4

Natural heavy-hole flopping mode qubit in germanium — •Philipp M. Mutter and Guido Burkard — University of Konstanz, Konstanz, Germany

Flopping mode qubits in double quantum dots allow for coherent spin-photon hybridization and fast qubit gates when coupled to either an alternating external or a quantized cavity electric field. To achieve this, however, electronic systems rely on synthetic spin-orbit interaction by means of a magnetic field gradient as a coupling mechanism. Here we theoretically show that this challenging experimental setup can be avoided in heavy-hole systems in germanium by utilizing the sizable cubic Rashba spin-orbit interaction. We argue that the resulting natural flopping mode qubit possesses highly tunable spin coupling strengths that allow for qubit gate times in the nanosecond range when the system is designed to function in an optimal operation mode which we quantify.

TT 10.3 Wed 10:45 H4

On-chip Stark tuning of deterministically fabricated quantum dot waveguide systems — Peter Schnauber, Jan Grosse, Arsenty Kaganskiy, Maximilian Ott, Pavel Anikin, Ronny Schmidt, •Sven Rodt, and Stephan Reitzenstein — Institute of Solid State Physics, Technische Universit'at Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany

On-chip quantum photonic circuits based on monolithic waveguides structures provide a compact and robust solution for setting up quantum logics and processors. The required structuring has already reached a very high level in different material systems but the monolithic integration of a number of single-photon emitters with identical emission wavelength is still a crux of the matter. We tackle this issue by deterministically integrating single InGaAs/GaAs quantum dots (QDs) into pin-doped GaAs/AlGaAs waveguides by in-situ electron-beam lithography (iEBL) [1]. This approach promises the integration of QDs with quasi-identical emission wavelength in combination with a fine-tuning mechanism via the quantum confined Stark effect. The wavelength accuracy in the pre-selection step of iEBL was about 0.2 nm which is nicely covered by tuning-range of about 0.4 nm when applying a bias voltage of up to 1.2 V. This paves the way for the fabrication of scalable quantum photonic circuits that rely on photon interference from multi emitters.

[1] P. Schnauber et al., APL Photonics 6, 050801 (2021)

TT 10.4 Wed 11:00 H4

Integration of NV-centers in nanodiamond in 1D photonic crystal cavities — •Jan Olthaus[1], Philip P.J. Schrinner[2], Carsten Schuck[2], and Doris E. Reiter[1] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]Institute of Physics, Center for NanoTechnology - CeNTech and Center for Soft Nanoscience - SoN, University of Münster, Germany

The scalable integration of single-photon emitters with photonic circuits remains a major hurdle for the realisation of quantum information technologies. Efficient integration requires an interface, combining low losses and high coupling strength between these components. Here, we show results for the coupling of nitrogen vacancy centers in nanodiamond to 1D on-substrate photonic crystal cavities. In the first step, we use 3D FDTD simulations to optimise the geometry of a on-substrate photonic crystal cavity based on tantalum pentoxide waveguides. Based on the optimised structures, we then analyse the coupling conditions, if a nanodiamond cluster of varying sizes is placed in different positions around the cavity center. We find that for a deterministic air-mode design, optimal coupling is achieved when placing the nanodiamond at the air-waveguide interface within the central air-hole. Then, we validate our results experimentally by placing nanodiamonds close to the determined optimal position. We measure antibunching of the integrated photoluminescence signal proving single-photon emission. The scalability of our approach is demonstrated by simultaneous readout of the electron-spin of two neighbouring devices in a optical detected magnetic resonance measurement.

TT 10.5 Wed 11:15 H4

Optoelectronic sampling of ultrafast electric transients with single quantum dots — •Sebastian Krehs[1], Alex Widhalm[1,2], Dustin Siebert[2], Nand Lal Sharma[1,3], Timo Langer[1], Björn Jonas[1], Dirk Reuter[1], Andreas Thiede[2], Jens Förstner[2], and Artur Zrenner[1] — [1]Paderborn University, Physics Department, Warburger Straße 100, 33098 Paderborn, Germany — [2]Paderborn University, Electrical Engineering Department, Warburger Straße 100, 33098 Paderborn, Germany — [3]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany

The use of quantum systems as sensors promises high sensitivity, high precision and access to nanoscale applications. In our work, we have pioneered optoelectronic sampling of ultrafast electric signals with low capacitance single quantum dots photodiodes as sensor devices [1]. Our concept exploits the Stark effect to convert a time-dependent electric signal into a time-dependent shift of the QD transition energy. Time resolved measurements of the shift can be measured by resonant ps laser spectroscopy with spectrally tunable photocurrent detection. With our method we are able to sample the laser synchronous output pulse of an ultrafast CMOS circuit at cryogenic temperatures. We demonstrate an impressive sub-20 ps time resolution and an amplitude resolution in the mV-range. Theoretical calculations show that the accuracy of our method is not affected or limited by a moderate timing jitter or the optical pulse width.

[1] http://arxiv.org/abs/2106.00994

15 min. break.

TT 10.6 Wed 11:45 H4

Bright Electrically Controllable Quantum-Dot-Molecule Devices Fabricated by In Situ Electron-Beam Lithography — •Johannes Schall[1], Marielle Deconinck[1], Nikolai Bart[2], Matthias Florian[3], Martin von Helversen[1], Christian Dangel[4], Ronny Schmidt[1], Lucas Bremer[1], Frederik Bopp[4], Isabell Hüllen[3], Christopher Gies[3], Dirk Reuter[5], Andreas D. Wieck[2], Sven Rodt[1], Jonathan J. Finley[4], Frank Jahnke[3], Arne Ludwig[2], and Stephan Reitzenstein[1] — [1]IFKP, TU Berlin, Germany — [2]LS AFP, Ruhr-Universität Bochum, Germany — [3]ITP, University of Bremen, Germany — [4]WSI, TU München, Germany — [5]Department Physik, Universität Paderborn, Germany

In quantum repeater networks it is of central importance to temporarily store and retrieve quantum information. Concepts based on quantum dot molecules (QDMs) promise storage times in excess of 1 ms. To make use of QDM based quantum memories, efficient coupling to flying qubits needs to be realized while maintaining precise electrical control. We report on the development of electrically tunable single-QDM devices with strongly enhanced broadband photon extraction efficiency. The quantum devices are based on stacked quantum dots in a pin-diode structure underneath a deterministically defined circular

Bragg grating using in situ electron beam lithography. We determine the photon extraction efficiency, demonstrate bias voltage dependent spectroscopy and measure excellent single-photon emission properties. The metrics make the developed QDM device an attractive building block for use in future photonic quantum networks.

TT 10.7 Wed 12:00 H4

Photon-number entanglement generated by sequential excitation of a two-level atom — Stephen C. Wein[1], Juan C. Loredo[2], Maria Maffei[3], Paul Hilaire[2], Abdou Harouri[2], Niccolo Somaschi[4], Aristide Lemaitre[2], Isabelle Sagnes[2], Loic Lanco[2,5], Olivier Krebs[2], Alexia Auffeves[3], Christoph Simon[1], Pascale Senellart[2], and •Carlos Anton-Solanas[2,6] — [1]Univ. of Calgary, Canada — [2]C2N-CNRS, France — [3]Inst. Neel-CNRS, France — [4]Quandela SAS, France — [5]Univ. Paris-Diderot, France — [6]Carl von Ossietzky Univ., Germany

During the spontaneous emission of light from an excited two-level atom, the atom briefly becomes entangled with the photonic field, producing the entangled state $\alpha|e,0\rangle + \beta|g,1\rangle$, where g and e are the ground and excited states of the atom, and 0 and 1 are the vacuum and single photon states [1].

We experimentally show that the spontaneous emission can be used to deliver on demand photon-number entanglement encoded in time [2]. By exciting a charged quantum dot (an artificial two-level atom) with two sequential π pulses, we generate a photon-number Bell state $\alpha|00\rangle + \beta|11\rangle$. We characterize the quantum properties of this state using time-resolved photon correlation measurements. We theoretically show that applying longer sequences of π pulses to a two-level atom can produce multipartite time-entangled states with properties linked to the Fibonacci sequence.

[1] V. Weisskopf, E. Wigner, Zeitschrift für Physik 63, 54 (1930). [2] S. C. Wein, et al., arXiv:2106.02049 (2021).

TT 10.8 Wed 12:15 H4

Evaluating Atomically Thin Quantum Emitters for Quantum Key Distribution — •Timm Gao[1], Martin v. Helversen[1], Carlos Anton-Solanas[2], Christian Schneider[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

Single photon sources are considered key building blocks for future quantum communication networks. In recent years, atomic monolayers of transition metal dichalcogenides (TMDCs) emerged as a promising material platform for the development of compact quantum light sources. In this work, we evaluate for the first time the performance of a single photon source based on a strain-engineered WSe_2 monolayer [1] for quantum key distribution (QKD). Employed in a QKD-testbed emulating the BB84 protocol, we analyze the single-photon purity in terms of $g^{(2)}(0)$ and secret key rates as well as quantum bit error rates to be expected in full implementations of QKD. Furthermore, we exploit routines for the performance optimization previously applied to quantum dot based single-photon sources [2]. Our work represents a major step towards the application of TMDC-based devices in quantum technologies.

[1] L. Tripathi et al., ACS Photonics 5, 1919-1926 (2018)
[2] T. Kupko et al., npj Quantum Inform. 6, 29 (2020)

TT 10.9 Wed 12:30 H4

Single Photon Emission from a topological cavity — •Jonathan Jurkat[1], Sebastian Klembt[1], Tristan H. Harder[1], Johannes Beierlein[1], Monika Emmerling[1], Tobias Huber[1], Christian Schneider[2], and Sven Höfling[1] — [1]Technische Physik, Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems, and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Institute of Physics, University of Oldenburg, 26129 Oldenburg, Germany

We measured the emission enhancement as well as single photon emission of a In(Ga)As quantum in spectral resonance with a topological defect mode. The emission was measured in a micro-photoluminescence setup under quasi resonant pumping with a pulsed laser. Spectral resonance was achieved by means of temperature tuning. The photonics lattice and topologically protected defect mode was implemented in an orbital Su-Schrieffer-Heeger chain. This zigzag chain of coupled micropillar devices was fabricated using molecular beam epitaxy in combination with an etch and overgrowth technique. These coupled resonators offer the exciting opportunity to combine a complex band structure formation with the emission of single localized quantum emitters.

TT 11: Focus Session: Facets of Many-Body Quantum Chaos (organised by Markus Heyl and Klaus Richter) (joint session DY/TT)

This session covers the same topics as the TT-DY-MA symposium with the same name and five invited speakers on Tuesday, September 28th.

Time: Wednesday 10:00–13:00 Location: H6

TT 11.1 Wed 10:00 H6

Probing many-body quantum chaos with quantum simulators using randomized measurements — Lata K Joshi[1,2], •Andreas Elben[1,2,3], Amit Vikram[4,5], Benoit Vermersch[1,2,6], Victor Galitski[4], and Peter Zoller[1,2] — [1]Center for Quantum Physics, University of Innsbruck, Innsbruck A-6020, Austria — [2]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Innsbruck A-6020, Austria — [3]Institute for Quantum Information and Matter and Walter Burke Institute for Theoretical Physics, California Institute of Technology, Pasadena, CA 91125, USA — [4]Joint Quantum Institute, University of Maryland, College Park, MD 20742, USA — [5]Condensed Matter Theory Center, Department of Physics, University of Maryland, College Park, MD 20742, USA — [6]Univ. Grenoble Alpes, CNRS, LPMMC, 38000 Grenoble, France

Randomized measurements provide a novel toolbox to probe many-body quantum chaos in quantum simulators, utilizing observables such as out-of-time ordered correlators and spectral form factors (SFFs). Here, I will focus on a protocol to access the SFF, characterizing the energy eigenvalue statistics, in quantum spin models. In addition, I will introduce partial spectral form factors (pSFFs) which refer to subsystems of the many-body system and reveal unique insights into energy eigenstate statistics. I will show that our randomized measurement protocol allows to access both, SFF and pSFFs. It provides thus a unified testbed to probe many-body quantum chaotic behavior, thermalization and many-body localization in closed quantum systems.

TT 11.2 Wed 10:15 H6

Exploring the bound on chaos due to quantum criticality — •Mathias Steinhuber, Juan-Diego Urbina, and Klaus Richter — University of Regensburg, Regensburg, Germany

The 'bound on chaos' proposed by Maldacena, Shenker and Stanford [1] predicts a temperature-dependent upper bound on the initial exponential growth rate $\lambda_{\mathrm{OTOC}} \leq 2\pi T$ for out-of-time-order correlators (OTOCs) in quantum systems with chaotic classical limit. We explore the temperature dependence of the quantum Lyapunov exponent λ_{OTOC} in Bose-Hubbard systems near criticality of the ground state [2]. We find the conditions for a non-trivial temperature dependence satisfying the bound, indicating the requirement that the system shows signatures of classical instability at the ground state while reaching the semiclassical regime at the same time. This is guaranteed by many-body systems with a well defined mean-field limit close to a bifurcation [3].

[1] Maldacena J., Shenker S. H. & Stanford D. A bound on chaos. Journal of High Energy Physics 2016, 106 (2016).

[2] Hummel, Q., Geiger, B., Urbina, J. D. & Richter, K. Reversible Quantum Information Spreading in Many-Body Systems near Criticality. Phys. Rev. Let. 123, 160401 (2019).

[3] Eilbeck, J., Lomdahl, P. & Scott, A. The discrete self-trapping

equation. Physica D: Nonlinear Phenomena 16, 318-338 (1985).

TT 11.3 Wed 10:30 H6

Critically slow operator dynamics in constrained many-body systems — •Johannes Feldmeier[1,2] and Michael Knap[1,2] — [1]Technical University of Munich — [2]Munich Center for Quantum Science and Technology (MCQST)

The far-from-equilibrium dynamics of generic interacting quantum systems is characterized by a handful of universal guiding principles, among them the ballistic spreading of initially local operators. Here, we show that in certain constrained many-body systems the structure of conservation laws can cause a drastic modification of this universal behavior. As an example, we study operator growth characterized by out-of-time-order correlations (OTOCs) in a dipole-conserving fracton chain. We identify a critical point with sub-ballistically moving OTOC front, that separates a ballistic from a dynamically frozen phase. This critical point is tied to an underlying localization transition and we use its associated scaling properties to derive an effective description of the moving operator front via a biased random walk with long waiting times. We support our arguments numerically using classically simulable automaton circuits.

TT 11.4 Wed 10:45 H6

Universal equilibration dynamics of the Sachdev-Ye-Kitaev model — •Soumik Bandyopadhyay, Philipp Uhrich, Alessio Paviglianiti, and Philipp Hauke — INO-CNR BEC Center and Department of Physics, University of Trento, Via Sommarive 14, I-38123 Trento, Italy

The Sachdev-Ye-Kitaev (SYK) model was introduced in the context of explaining the properties of "strange metals," and has been found to manifest the characteristics of a quantum theory which is holographically dual to extremal charged black holes with two-dimensional anti-de Sitter horizons. Being maximally chaotic, black holes are the best known scramblers of quantum information in nature. Same features are shared by the SYK model, which has triggered a massive interest in its chaotic dynamics. Yet, many questions about the dynamics of the SYK model remain open. In this presentation, we shall be discussing the equilibration process of a fermionic system under the SYK Hamiltonian evolution. Our study, based on a state-of-the-art exact diagonalization method, reveals that the system exhibits an universal equilibration process. By devising a master equation for disordered systems, we successfully explain some of the key features of this dynamics. We infer the universality from the spectral analysis of the corresponding Liouvillian. We expect our findings shed light on challenging questions for systems far from equilibrium, such as, thermalization of closed and disordered quantum many-body systems.

TT 11.5 Wed 11:00 H6

Periodic orbit sums and their relation to JT gravity correlators — •Fabian Haneder, Torsten Weber, Camilo Moreno, Juan Diego Urbina, and Klaus Richter — University of Regensburg, Germany

Jackiw-Teitelboim (JT) gravity is a two-dimensional dilaton gravity theory originally used to describe the near-horizon physics of charged, static black holes, but has recently garnered much attention due to its exact duality to a particular double-scaled Hermitian matrix model [1]. Applications are believed to be as a toy model for the black hole information paradox, the AdS/CFT correspondence, and holography and quantum gravity more generally.

The duality with a matrix model suggests the existence of a classical chaotic system which, after semiclassical (periodic orbit) quantisation [2], leads to the same spectral correlations. Finding such a system would solve the long-standing problem of identifying a single dual, rather than an ensemble of theories, as expected from orthodox AdS/CFT.

In this contribution, we will give a very brief overview of the JT/matrix model duality and show the structural similarity of JT correlators and stochastically projected periodic orbit sums, at the level of the one-point function, as well as propose a candidate dual system.

[1] P. Saad, S. Shenker, D. Stanford, arXiv:1903.11115

[2] See e.g. M. Gutzwiller, *Chaos in classical and quantum mechanics*, Springer 2019

TT 11.6 Wed 11:15 H6

Entanglement entropy of fractal states — Giuseppe De Tomasi[1] and •Ivan Khaymovich[2] — [1]T.C.M. Group, Cavendish Laboratory, JJ Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [2]Max Planck Institute for the Physics of Complex Systems

In this talk we will discuss the relations between entanglement (and Renyi) entropies and fractal dimensions D_q of many-body wavefunctions.

As a simple example we introduce a new class of *sparse* random pure states being fractal in the corresponding computational basis and show that their entropies reach the upper bound of Page value for fractal dimension larger than the subsystem size ($D_q > 0.5$ for equipartitioning) and grow linearly with D_q otherwise.

Moreover this dependence poses the upper bound for entanglement and Renyi entropies for any multifractal states and uncovers the relation between multifractality and entanglement properties of many-body wavefunctions.

15 min. break.

TT 11.7 Wed 11:45 H6

Chaos for Interacting Bosons and Random Two-Body Hamiltonians — Lukas Pausch[1], Edoardo Carnio[1,2], Andreas Buchleitner[1,2], and •Alberto Rodríguez[3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität-Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [3]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain

We investigate the chaotic phase of the Bose-Hubbard model [1] in relation to the bosonic embedded random-matrix ensemble, which mirrors the dominant few-body nature of many-particle interactions, and hence the Fock space sparsity of quantum many-body systems. Within the chaotic regime, mean and fluctuations of the fractal dimensions of Bose-Hubbard eigenstates show clear fingerprints of ergodicity and are well described by the embedded ensemble, which is furthermore able to capture the energy dependence of the chaotic phase. Despite such agreement, the distributions of the fractal dimensions for these two models depart from each other and from the Gaussian orthogonal ensemble as Hilbert space grows.

[1] L. Pausch et al, Phys. Rev. Lett. **126**, 150601 (2021).

TT 11.8 Wed 12:00 H6

Orthogonal quantum many-body scars — •Hongzheng Zhao[1], Adam Smith Smith[2], Florian Mintert[1], and Johannes Knolle[1,3,4] — [1]Blackett Laboratory, Imperial College London, London, United Kingdom — [2]School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, United Kingdom — [3]Department of Physics TQM, Technical University of Munich, Munich, Germany — [4]Munich Center for Quantum Science and Technology, Munich, Germany

Quantum many-body scars have been put forward as counterexamples to the Eigenstate Thermalization Hypothesis. These atypical states are observed in a range of correlated models as long-lived oscillations of local observables in quench experiments starting from selected initial states. The long-time memory is a manifestation of quantum non-ergodicity generally linked to a sub-extensive generation of entanglement entropy, the latter of which is widely used as a diagnostic for identifying quantum many-body scars numerically as low entanglement outliers. Here we show that, by adding kinetic constraints to a fractionalized orthogonal metal, we can construct a minimal model with orthogonal quantum many-body scars leading to persistent oscillations with infinite lifetime coexisting with rapid volume-law entanglement generation. Our example provides new insights into the link between quantum ergodicity and many-body entanglement while opening new avenues for exotic non-equilibrium dynamics in strongly correlated multi-component quantum systems. Reference: https://arxiv.org/abs/2102.07672

TT 11.9 Wed 12:15 H6

Genuine many-body quantum scarring in a periodic Bose-Hubbard ring — •Quirin Hummel and Peter Schlagheck — Université de Liège (Belgium)

Quantum scars have been known for decades to exist in quantum systems of low dimensionality (e.g. "quantum billiards"): While most eigenstates of a classically chaotic system are typically spread across the accessible phase space, individual states exist that are concentrated along unstable classical periodic orbits. On the other hand, recent studies in many-body quantum systems that admit no known meaningful classical limits have revealed eigenstates - now termed "quantum many-body scars" - that feature quantum mechanical properties reminiscent of scenarios of quantum scarring. An unambiguous classification as scars in the original sense, however, remains controversial, if not fundamentally impossible due to the lack of a classical limit. In order to bridge this gap, we investigate the phenomenon of quantum scarring in the prototypical Bose-Hubbard model, a many-body quantum system that combines both, a well-defined formally classical description and the typical high-dimensionality of many-body systems identified with the number of sites that constitute the one-body state space.

TT 11.10 Wed 12:30 H6

Quantum scars of bosons with correlated hopping — •Ana Hudomal[1,2], Ivana Vasić[2], Nicolas Regnault[3,4], and Zlatko Papić[1] — [1]School of Physics and Astronomy, University of Leeds, United Kingdom — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Joseph Henry Laboratories and Department of Physics, Princeton University, USA — [4]Laboratoire de Physique de l'École Normale Supérieure, ENS, CNRS, Paris, France

Recent experiments have shown that preparing an array of Rydberg atoms in a certain initial state can lead to unusually slow thermalization and persistent density oscillations [1]. This type of non-ergodic behavior has been attributed to the existence of "quantum many-body scars", i.e., atypical eigenstates that have high overlaps with a small subset of vectors in the Hilbert space. Periodic dynamics and many-body scars are believed to originate from a "hard" kinetic constraint: due to strong interactions, no two neighbouring Rydberg atoms are both allowed to be excited. Here we propose a realization of quantum many-body scars in a 1D bosonic lattice model with a "soft" constraint: there are no restrictions on the allowed boson states, but the amplitude of a hop depends on the occupancy of the hopping site. We find that this model exhibits similar phenomenology to the Rydberg atom chain, including weakly entangled eigenstates at high energy densities and the presence of a large number of exact zero energy states [2].

[1] H. Bernien et al., Nature **551**, 579 (2017).
[2] A. Hudomal et al., Commun. Phys. **3**, 99 (2020).

TT 11.11 Wed 12:45 H6

Quantum local random networks and the statistical robustness of quantum scars — •Federica Maria Surace[1,2], Marcello Dalmonte[1,2], and Alessandro Silva[1] — [1]International School for Advanced Studies (SISSA), via Bonomea 265, 34136 Trieste, Italy — [2]The Abdus Salam International Centre for Theoretical Physics (ICTP), Strada Costiera 11, 34151 Trieste, Italy

We investigate the emergence of quantum scars in a general ensemble of random Hamiltonians (of which the PXP is a particular realization), that we refer to as quantum local random networks. We find two types of scars, that we call stochastic and statistical. We identify specific signatures of the localized nature of these eigenstates by analyzing a combination of indicators of quantum ergodicity and properties related to the network structure of the model. Within this parallelism, we associate the emergence of statistical scars to the presence of motifs in the network, that reflects how these are associated to links with anomalously small connectivity (as measured, e.g., by their betweenness). Most remarkably, statistical scars appear at well-defined values of energy, predicted solely on the basis of network theory. We study the scaling of the number of statistical scars with system size: below a threshold connectivity, we find that the number of statistical scars increases with system size. This allows to define the concept of statistical stability of quantum scars.

TT 12: New Experimental Techniques

Time: Wednesday 10:00–11:00 Location: H7

TT 12.1 Wed 10:00 H7

Chip-based magnetic levitation of superconducting microparticles for macroscopic quantum experiments — •Marti Gutierrez[1], Achintya Paradkar[1], Gerard Higgins[1,2], and Witlef Wieczorek[1] — [1]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Kemivagen 9, SE-412 96 Gothenburg, Sweden — [2]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, Vienna, A-1090, Austria

In this work, we demonstrate chip-based magnetic levitation of superconducting microparticles. Magnetic levitation has been proposed as a platform to decouple the center-of-mass (COM) motion of a levitated mechanical resonators from the environment. As a result, this platform enables the development of novel, ultra-sensitive force and acceleration sensors, as well as performing quantum experiments with macroscopic objects of 10^13 atomic mass units. Our approach is based on an integrated magnetic trap consisting of a two-chip stack with microfabricated niobium superconducting coils. We further fabricate near spherical lead spheres of sub-100um diameter. A pair of integrated coils is used to generate the magnetic trapping field, while additional coils are used for SQUID-based detection and, independently, for feedback-based manipulation of the COM motion of the levitated particle. We show first trapping experiments, where we observe the motion of the levitated particle optically and via SQUID-based read-out. In future experiments, we aim to couple the levitated particle to superconducting circuits, in order to perform quantum control over its COM motion.

TT 12.2 Wed 10:15 H7

Reaching the ultimate energy resolution of a quantum detector — •Bayan Karimi[1], Fredrik Brange[1,2], Danilo Nikolic[3], Joonas T. Peltonen[1], Peter Samuelsson[2], Wolfgang Belzig[3], and Jukka P. Pekola[1] — [1]QuESTech and QTF Centre of Excellence, Department of Applied Physics, Aalto University, Finland — [2]Department of Physics and NanoLund, Lund University, Sweden — [3]QuESTech and Fachbereich Physik, Universität Konstanz, Germany

We demonstrate experimentally detection of equilibrium fluctuations of temperature in a system of about 10^8 electrons exchanging energy with phonon bath at a fixed temperature [1]. In this experiment, we employ a radio-frequency thermometer, connected to a nanocalorimeter, based on a zero-bias anomaly of a tunnel junction between a superconductor and proximitized normal metal [2,3]. It features noninvasive detection and essentially uncompromised sensitivity down to the lowest temperatures of below 20 mK. We show theoretically that this detector is capable of observing single microwave photons in a continuous manner [4,5].

[1] B. Karimi, F. Brange, P. Samuelsson, J. P. Pekola, Nat. Commun. **11**, 367 (2020)
[2] B. Karimi and J. P. Pekola, Phys. Rev. Appl. **10**, 054048 (2018)
[3] B. Karimi, D. Nikolić, T. Tuukkanen, J. T. Peltonen, W. Belzig, J. P. Pekola, Phys. Rev. Applied **13**, 054001 (2020)
[4] B. Karimi and J. P. Pekola, Phys. Rev. Lett. **124**, 170601 (2020)
[5] J. P. Pekola and B. Karimi, arXiv:2010.11122 (2020)

TT 12.3 Wed 10:30 H7

Towards time domain phase diagram of metastable charge-ordered states — •Yaroslav Gerasimenko[1,2], Jan Ravnik[1,3], Jaka Vodeb[1], Michele Diego[1], Yevhenii Vaskivskyi[1], Viktor Kabanov[1], Igor Vaskivskyi[1], Tomaz Mertelj[1], and Dragan Mihailovic[1] — [1]Jozef Stefan Institute, Ljubljana, Slovenia — [2]University of Regensburg, Regensburg, Germany — [3]PSI, Villigen, Switzerland

Metastable self-organized electronic states in quantum materials are emergent states of matter[1] typically formed through phase transitions under non-equilibrium conditions. It is of fundamental importance to understand the process of their formation that can involve multiple mechanisms[1,2] spanning a large range of timescales.

Here we combine multiple techniques to map the evolution of metastable states in 1T-TaS_2, a prototypical charge-ordered quantum material, using the photon density and temperature as control parameters on timescales ranging from 10^{-12} to 10^3 s. The combination of STM and in situ ultrafast excitation allows us to observe explicitly both parametric stability and nanoscale relaxation of the light-induced metastable states on the scale of seconds, while time-resolved optical techniques and electrical measurements allow us to study the ordering and relaxation processes down to a few picoseconds. [3]

[1] Ya. A. Gerasimenko et al., Nat. Mater. 18, 1078-1083 (2019)
[2] Ya. A. Gerasimenko et al., npj Quantum Materials 4, 1-9 (2019)
[3] J. Ravnik et al., Nat. Comm. 12, 2323 (2021)

TT 12.4 Wed 10:45 H7

Advanced technique for probing critical elasticity in strongly coupled electron-phonon systems — •Yassine Agarmani, Jan Zimmermann, Steffi Hartmann, Bernd Wolf, and Michael Lang — Institute of Physics, Goethe University Frankfurt, Germany

The recently proposed phenomena of critical elasticity arises from a non-perturbative coupling between lattice and critical electronic degrees of freedom. As demonstrated for the Mott insulator κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Cl, tuning to the critical endpoint of the first order Mott transition cause a vanishing elastic modulus and a violation of Hooke's law of elasticity [1, 2]. Similar effects are expected to surround the critical region of the valence transition in EuPd$_2$Si$_2$. Measurements of relative length changes under control of temperature and pressure have proven a most sensitive tool for investigating this phenomenon of critical elasticity. In order to develope a deeper understanding of critical elasticity, an expansion of the setup used in Ref. [2] has been designed and realized. It consists of two identical capacitive dilatometer systems, the temperature of which can be controlled individually, and which are connected to a He-gas pressure reservoir. We discuss the new possibilities this system offers for performing high-resolution measurements of relative length changes over wide ranges of temperature and pressure.

[1] Zacharias *et al.*, Eur. Phys. J. Spec. Top. 224, 1021-1040 (2015)
[2] Gati *et al.*, Sci. Adv. 2, e1601646 (2016)

TT 13: Quantum Computing (joint session TT/DY)

Time: Wednesday 11:15–13:00 Location: H7

TT 13.1 Wed 11:15 H7

Probing the critical current coupling of defects in Josephson junctions — •Alexander Konstantin Neumann[1], Benedikt Berlitz[1], Alexey V. Ustinov[1,2,3], and Jürgen Lisenfeld[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]National University of Science and Technology MISIS, Moscow 119049, Russia — [3]Russian Quantum Center, Skolkovo, Moscow 143025, Russia

Material defects form a major source of decoherence in state of the art superconducting quantum bits. It has been a long standing question whether defects residing in the tunnel barrier of Josephson junctions modify their critical current. We investigate this with spectroscopic measurements and QuTiP simulations on individual defects strongly coupled to a transmon qubit. By observing avoided level crossings at driving amplitudes allowing for multi-photon transitions, we quantify the strength of the critical current coupling. Moreover, we find an effective direct interaction between the defect and the qubit's readout resonator, providing an additional decoherence channel.

TT 13.2 Wed 11:30 H7

Cavity mediated quantum gate between distant charge qubits — •Florian Kayatz, Jonas Mielke, and Guido Burkard — Department of Phyiscs, University of Konstanz, Konstanz, Germany

Gate based quantum computers require high fidelity single-qubit and two-qubit gates to allow for arbitrary multi-qubit operations that are needed to perform a quantum algorithm. Ideally, one has "all-to-all" connectivity, i.e. an architecture with two-qubit gates between any desired pair of qubits. Notably, short-ranged interactions such as capacitive coupling and the exchange interaction cannot be harnessed to implement two-qubit gates between distant qubits. We investigate whether a high-fidelity iSWAP gate between distant charge qubits can be implemented by using a microwave resonator as an intermediate system mediating the interaction. In particular, we consider charge qubits formed by a single electron confined in a Si double quantum dot that are coupled to a microwave resonator via electric dipole coupling. We theoretically demonstrate that, in the dispersive regime, the photons can mediate an iSWAP gate. We then calculate the gate fidelity in the presence of the dominant noise sources, quasi-static charge noise, resonator damping and phonon induced charge relaxation, and find a very limited gate fidelity.

TT 13.3 Wed 11:45 H7

Crosstalk analysis for single-qubit and two-qubit gates in spin qubit arrays — •Irina Heinz and Guido Burkard — University of Konstanz, Konstanz, Germany

Scaling up spin qubit systems requires high-fidelity single-qubit and two-qubit gates. Gate fidelities exceeding 98% were already demonstrated in silicon based single and double quantum dots, whereas for the realization of larger qubit arrays crosstalk effects on neighboring qubits must be taken into account. We analyze qubit fidelities impacted by crosstalk when performing single-qubit and two-qubit operations on neighbor qubits with a simple Heisenberg model. Furthermore we propose conditions for driving fields to robustly synchronize Rabi oscillations and avoid crosstalk effects. In our analysis we also consider next to nearest neighbor crosstalk and show that double synchronization leads to a restricted choice for the driving field strength, exchange interaction, and thus gate time. Considering realistic experimental conditions we propose a set of parameter values to perform a nearly crosstalk-free CNOT gate and so open up the pathway to scalable quantum computing devices.

TT 13.4 Wed 12:00 H7

Spin shuttling in a silicon double quantum dot — •Florian Ginzel[1], Adam R. Mills[2], Jason R. Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

The transport of quantum information between different nodes of the device is crucial for a quantum processor. In the context of spin qubits, this can be realized by coherent electron spin shuttling between quantum dots. Here we theoretically study a minimal version of spin shuttling between two quantum dots (QDs) occupied by one electron [1]. We analyze the possibilities and limitations of spin transport during a detuning sweep in a silicon double QD. This research is motivated by recent experimental progress [2,3]. Spin-orbit interaction and an inhomogeneous magnetic field play an important role for spin shuttling and are included in our model. Interactions that couple the position, spin and valley degrees of freedom open avoided crossings in the spectrum allowing for diabatic transitions and interfering paths. The outcomes of single and repeated spin shuttling protocols are explored by means of numerical simulations and an approximate analytic model based on the Landau-Zener model. We find that fast high-fidelity spin-shuttling is feasible for optimal choices of parameters or protected by constructive interference.

[1] Ginzel et al., Phys. Rev. B 102, 195418 (2020)
[2] T. Fujita et al., npj Quantum Information 3, 22 (2017)
[3] A. R. Mills et al., Nat. Comm. 10, 1063 (2019)

TT 13.5 Wed 12:15 H7

Simulating hydrodynamics on NISQ devices with random circuits — •Jonas Richter and Arijeet Pal — Department of Physics and Astronomy, University College London, UK

We show that pseudorandom circuits, recently implemented in Google's seminal "quantum supremacy" experiment, are not just abstract tools to outperform classical computers, but in fact form tailormade building blocks to simulate certain aspects of quantum many-body systems on noisy intermediate-scale quantum computers. Specifically, we propose an algorithm consisting of a random circuit followed by a trotterized Hamiltonian time evolution to study transport properties in the linear response regime, which we numerically exemplify for one- and two-dimensional quantum spin systems. While the algorithm operates without an overhead of bath or ancilla qubits for initial-state preparation and measurement, our numerics further suggest that it is comparatively robust against systematic Trotter errors and noisy gates.

[1] J. Richter and A. Pal, Phys. Rev. Lett. 126, 230501 (2021)

TT 13.6 Wed 12:30 H7

Adaptive variational NISQ quantum algorithms for dynamics and excited states preparation — Yongxin Yao[1,2], Niladri Gomes[1,2], Feng Zhang[1,2], Cai-Zhuang Wang[1,2], Kai-Ming

Ho[1,2], Thomas Iadecola[1,2], and •Peter P. Orth[1,2] — [1]Ames Laboratory, Ames, Iowa, USA — [2]Iowa State University, Ames, Iowa, USA

Simulating quantum dynamics of interacting many-body systems is one of the main potential applications of quantum computing, since the growth of entanglement makes such simulations exponentially hard on classical devices. The shallow circuit requirement of current QPUs limits algorithms based on Trotter product formulas to simulate early time dynamics. Here, we present an adaptive approach to construct a variational wave function ansatz for accurate quantum dynamics simulations based on McLachlan's variational principle [1]. The key idea is to dynamically expand the variational ansatz along the time-evolution path such that the McLachlan distance, which is a measure of the simulation accuracy, remains below a set threshold. We apply this adaptive variational quantum dynamics simulation approach (non)integrable quantum spin models and find the circuits to contain up to two orders of magnitude fewer CNOT gates than those obtained from first-order Trotter expansion. We also present results on development of an adaptive VQE-X algorithm for preparation of highly excited states in many-body models [2].

[1] Yao et al., PRX Quantum 2, 030307 (2021)
[2] Zhang et al., arXiv:2104.12636 (2021)

TT 13.7 Wed 12:45 H7

Simulating a discrete time crystal over 57 qubits on a quantum computer — •Philipp Frey and Stephan Rachel — School of Physics, University of Melbourne, Parkville, VIC 3010, Australia

We simulate the dynamics of a spin-1/2 chain with nearest neighbor Ising interactions, quenched disorder and periodic driving over 57 qubits on a current quantum computer. Based on the dynamics of local spin depolarisation we observe discrete time crystalline (DTC) behaviour due to many body localisation (MBL). We probe random initial states along with fully polarised states and compare the cases of vanishing and finite disorder to distinguish MBL from pre-thermal dynamics. In order to extract the signal from the noisy data produced by current quantum computer devices, we develop a strategy for error mitigation and show that the results are robust under variations of the parameters introduced in this scheme. A transition between DTC and a thermal phase is observed via critical fluctuations in the sub-harmonic frequency response of the system, as well as a significant speed-up of spin depolarisation. Our findings are consistent with previous numerical simulations, but represent the realization of a DTC with largest system size to date.

TT 14: Many-Body Quantum Dynamics I (joint session DY/TT)

Time: Wednesday 13:30–14:45 Location: H6

Invited Talk TT 14.1 Wed 13:30 H6

Nanofriction in Ion Coulomb Systems — •Tanja Mehlstäubler — PTB, Bundesallee 100, 38116 Braunschweig

Single trapped and laser-cooled ions in Paul traps allow for a high degree of control of atomic quantum systems. They are the basis for modern atomic clocks, quantum computers and quantum simulators. Our research aims to use ion Coulomb crystals, i.e. many-body systems with complex dynamics, for precision spectroscopy. This paves the way to novel optical frequency standards for applications such as relativistic geodesy and quantum simulators in which complex dynamics becomes accessible with atomic resolution. The high-level of control of self-organized Coulomb crystals opens up a fascinating insight into the non-equilibrium dynamics of coupled many-body systems, displaying atomic friction and symmetry-breaking phase transitions. We discuss the creation of topological defects and Kibble-Zurek tests in 2D crystals and present recent results on the study of tribology and transport mediated by the topological defect.

TT 14.2 Wed 14:00 H6

Quantum many-body scars in tilted Fermi-Hubbard chains — •Jean-Yves Desaules[1], Ana Hudomal[1,2], Christopher Turner[1], and Zlatko Papić[1] — [1]School of Physics and Astronomy, University of Leeds, Leeds, United Kingdom — [2]Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia

Motivated by recent observations of ergodicity breaking due to Hilbert space fragmentation in 1D Fermi-Hubbard chains with a tilted potential [Scherg et al., arXiv:2010.12965], we show that the same system also hosts quantum many-body scars in a regime $U=\Delta>J$ at electronic filling factor $\nu=1$. We numerically demonstrate that the scarring phenomenology in this model is similar to other known realisations such as Rydberg atom chains, including persistent dynamical revivals and ergodicity-breaking many-body eigenstates. At the same time, we show that the mechanism of scarring in the Fermi-Hubbard model is different from other examples in the literature: the scars originate from a subgraph, representing a free spin-1 paramagnet, which is weakly connected to the rest of the Hamiltonian's adjacency graph. Our work demonstrates that correlated fermions in tilted optical lattices provide a platform for understanding the interplay of many-body scarring and other forms of ergodicity breaking, such as localisation and Hilbert space fragmentation.

TT 14.3 Wed 14:15 H6

(Classical) Prethermal phases of matter — •Andrea Pizzi[1], Andreas Nunnenkamp[2], and Johannes Knolle[3] — [1]Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United Kingdom — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [3]Department of Physics, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany

Systems subject to a high-frequency drive can spend an exponentially long time in a prethermal regime, in which novel phases of matter with no equilibrium counterpart can be realized. Due to the notorious computational challenges of quantum many-body systems, numerical investigations in this direction have remained limited to one spatial dimension, in which long-range interactions have been proven a necessity. Here, we show that prethermal non-equilibrium phases of matter are not restricted to the quantum domain. Studying the Hamiltonian dynamics of a large three-dimensional lattice of classical spins, we provide the first numerical proof of prethermal phases of matter in a system with short-range interactions. Concretely, we find higher-order as well as fractional discrete time crystals breaking the time-translational symmetry of the drive with unexpectedly large integer as well as fractional periods. Our work paves the way towards the exploration of novel prethermal phenomena by means of classical Hamiltonian dynamics with virtually no limitations on the system's geometry or size, and thus with direct implications for experiments.

TT 14.4 Wed 14:30 H6

Master equations for Wigner functions with spontaneous collapse and their relation to thermodynamic irreversibility* — •Michael te Vrugt[1,2], Gyula I. Tóth[3], and Raphael Wittkowski[1] — [1]Institut für Theoretische Physik, Center for Soft Nanoscience, Westfälische Wilhelms-Universität Münster, D-48149 Münster, Germany — [2]Philosophisches Seminar, Westfälische Wilhelms-Universität Münster, D-48143 Münster, Germany — [3]Interdisciplinary Centre for Mathematical Modelling and Department of Mathematical Sciences, Loughborough University, Loughborough, LE11 3TU, United Kingdom

Wigner functions allow for a reformulation of quantum mechanics in phase space. They are, as shown in our recent work [1], very useful for understanding effects of spontaneous collapses of the wavefunction as predicted by the Ghirardi-Rimini-Weber (GRW) theory. We derive the dynamic equations for the Wigner function in the GRW theory and its most important variants. The results are used to test, via computer simulations, David Albert's suggestion that the stochasticity induced by spontaneous collapses is responsible for the emergence of thermodynamic irreversibility. We do not observe the equilibration mechanism proposed by Albert, suggesting that GRW theory cannot explain the approach to thermal equilibrium.

[1] M. te Vrugt, G. I. Tóth, R. Wittkowski, arXiv:2106.00137 (2021)

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TT 15: Many-Body Quantum Dynamics II (joint session DY/TT)

Time: Thursday 10:00–11:30 Location: H2

TT 15.1 Thu 10:00 H2

Anderson localization of composite particles — •Fumika Suzuki[1], Mikhail Lemeshko[2], Wojciech Zurek[3], and Roman Krems[4] — [1]IST Austria (Institute of Science and Technology Austria) — [2]IST Austria (Institute of Science and Technology Austria) — [3]Los Alamos National Laboratory — [4]University of British Columbia

We investigate the effect of coupling between translational and internal degrees of freedom of composite quantum particles on their localization in a random potential. We show that entanglement between the two degrees of freedom weakens localization due to the upper bound imposed on the inverse participation ratio by purity of a quantum state. We perform numerical calculations for a two-particle system bound by a harmonic force in a 1D disordered lattice and a rigid rotor in a 2D disordered lattice. We illustrate that the coupling has a dramatic effect on localization properties, even with a small number of internal states participating in quantum dynamics.

arXiv:2011.06279

TT 15.2 Thu 10:15 H2

An SYK-inspired model with density-density interactions — •Johannes Dieplinger[1], Soumya Bera[2], and Ferdinand Evers[1] — [1]Institute of Theoretical Physics, University of Regensburg, D-93040, Germany — [2]Department of Physics, Indian Institute of Technology Bombay, Mumbai 400076, India

Strong electron-electron interactions are challenging to capture theoretically. A rare example of an analytically tractable model is the Sachdev-Ye-Kitaev (SYK) model, which owes its tractability to the structureless and therefore artificial design: interactions are restricted to two body terms, whose matrix elements are randomly chosen and therefore do not commute with the local density, a fundamental symmetry of realistic electron-electron interactions. We here investigate a derivative of the SYK model, restoring this fundamental symmetry [1]. It features density-density-type interactions as well as a randomized single body term. We present numerical evidence that this model has a rich phase structure, featuring two integrable phases separated by several intermediate phases, including a chaotic one. The latter exhibits several key characterstics of the SYK model including the spectral and wave function statistics and therefore should be adiabatically connected to the non-Fermi liquid phase of the original SYK model. Thus, the presented model provides a further element for bridging the SYK-model and microscopic realism.

[1] J. Dieplinger, S. Bera, F. Evers, Annals of Physics, 168503 (2021)

TT 15.3 Thu 10:30 H2

Disorder-Free Localization in an Interacting 2D Lattice Gauge Theory — •Peter Karpov[1,2], Roberto Verdel[1], Yi-Ping Huang[3], Markus Schmitt[4], and Markus Heyl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]National Univesity of Science and Technology "MISiS", Moscow, Russia — [3]National Tsing Hua University, Hsinchu, Taiwan — [4]University of Cologne, Cologne, Germany

Disorder-free localization has been recently introduced as a mechanism for ergodicity breaking in low-dimensional homogeneous lattice gauge theories caused by local constraints. We show that also genuinely interacting systems in two spatial dimensions can become nonergodic due to this mechanism. This is all the more surprising since the conventional many-body localization is conjectured to be unstable in two dimensions; hence the gauge constraints represent an alternative robust localization mechanism for interacting models in higher dimensions.

Specifically, we demonstrate nonergodic behavior in the quantum link model by obtaining a bound on the localization-delocalization transition through a unconventional percolation problem implying a fragmentation of Hilbert space. We study the quantum dynamics in this system by introducing the method of "variational classical networks", an efficient representation of the wave function in terms of a network of classical spins. We show that propagation of line defects has different light cone structures in the localized and ergodic phases.

[1] P. Karpov et al, Phys. Rev. Lett. **126**, 130401 (2021).
[2] R. Verdel et al, Phys. Rev. B **103**, 165103 (2021).

TT 15.4 Thu 10:45 H2

Superradiant many-qubit absorption refrigerator — Michal Kloc[1], Kurt Meier[1], Kimon Hadjikyriakos[2], and •Gernot Schaller[3] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328, Dresden, Germany

We show that the lower levels of a large-spin network with a collective anti-ferromagnetic interaction and collective couplings to three reservoirs may function as a quantum absorption refrigerator. In appropriate regimes, the steady-state cooling current of this refrigerator scales quadratically with the size of the working medium, i.e., the number of spins. The same scaling is observed for the noise and the entropy production rate.

[1] arXiv:2106.04164

TT 15.5 Thu 11:00 H2

Bose condensation of squeezed light — •Klaus Morawetz — Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics-UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil

Light with an effective chemical potential and no mass is shown to possess a general phase-transition curve to Bose-Einstein condensation. This limiting density and temperature range is found by the diverging in-medium potential range of effective interaction. While usually the absorption and emission with Dye molecules is considered, here it is proposed that squeezing can create also such an effective chemical potential. The equivalence of squeezed light with a complex Bogoliubov transformation of interacting Bose system with finite lifetime is established with the help of which an effective gap is deduced. This gap phase creates a finite condensate in agreement with the general limiting density and temperature range. The phase diagram for condensation is presented due to squeezing and the appearance of two gaps is discussed. Phys. Rev. B 99 (2019) 205124

TT 15.6 Thu 11:15 H2

Interplay of thermal and plasmonic THz nonlinearities on graphene — Jeongwoo Han[1], Mattew L. Chin[2], •Stephan Winnerl[3], Thomas E. Murphy[2], and Martin Mittendorff[1] — [1]Department of Physics, University of Duisburg-Essen, 47057 Duisburg, Germany — [2]University of Maryland, College Park, MD 20740, United States of America — [3]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

Due to the linear dispersion, graphene has attracted much attention as a material platform of nonlinear optics, in particular in the infrared regime. While for higher photon energies the nonlinearities are mostly related to interband transitions and Pauli blocking, in the infrared regime intraband and thermal effects dominate. Here we present the experimental evidence of nonlinear THz absorption beyond thermal effects, i.e., plasmonic nonlinearity, by employing polarization-resolved terahertz pump-probe measurements on graphene disks. By varying the polarization between pump and probe beam, i.e., co- and cross-polarized configurations, we observe a significant polarization dependence of the pump-induced change in transmission. To quantitatively analyze this observation, we develop numerical simulation, allowing us to understand the interplay between thermal and plasmonic nonlinearities. While both contribute to the co-polarized configuration, thermal effects dominate the nonlinearity in the cross-polarized configuration.

TT 16: PhD Focus Session: Symposium on Strange Bedfellows - Magnetism Meets Superconductivity" (joint session MA/AKjDPG) (joint session MA/TT)

At first sight, it seems that the phenomena of magnetism and superconductivity do not go along, as indicated by the Meissner effect, when a magnetic field is completely expelled from the interior of a conventional superconductor. However, the synergy of these two manifestations of nature in condensed matter does occur and can be rather interesting! Theoretical works have predicted the existence of exotic states at the interface between a superconductor and a magnet, such as the sought-after Majorana fermions and spin-triplet superconductivity. The first have been predicted to route an efficient way to implement quantum computers (currently a European scientific flagship), while the latter allows the creation of spin-polarized supercurrents, opening up fundamentally new possibilities for spintronics. Therefore, our symposium aims at putting together experts to provide a fundamental and practical understanding of the subject to discuss most recent developments from the theoretical and experimental sides, and to show perspectives for applications.

Organizers: Annika Stellhorn, Flaviano José dos Santos, Markus Hoffmann (Forschungszentrum Jülich and Peter Grünberg Institut)

Time: Thursday 10:00–12:45 Location: H5

Invited Talk TT 16.1 Thu 10:00 H5

Magnetism and superconductivity: new physics one atom at a time — •Alexander Balatsky — NORDITA — UCONN

In this tutorial I will review the effects of magnetism and electronic defect in conventional and unconventional superconductors. The extreme case of quantum engineering where one builds magnetic and electronic features one atom at a time has proved to be a versatile approach. Impurities and defects are pair breakers in superconductors. I will discuss how defects can also enable new features in superconductors like intragap resonances, topological Majorana modes and seed new superconducting phases. Looking forward I will discuss how we might induce novel physics in superconductors with precise quantum impurity band engineering

TT 16.2 Thu 10:30 H5

Magnetic exchange interactions at proximity of a superconductor — •Uriel Aceves[1,2], Sascha Brinker[1], Filipe Guimaraes[3], and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany — [3]Jülich Supercomputing Centre, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany

The coupling of magnetic impurities to superconductors prompts the arise of exciting physics such as sub-gap states like Yu-Shiba-Rusinov states and Majorana zero modes, which constitute key mechanisms on the road towards a topological quantum computer. The interplay of spin-orbit coupling and (non-collinear) magnetism enriches the complexity and topological nature of the in-gap states hosted in proximity-induced superconductors. However, little is known about the impact of superconductivity on the different contributions to the magnetic exchange interactions, like the bilinear isotropic exchange and the Dzyaloshinskii-Moriya interaction — and in turn the impact on the magnetic textures. In this work, we propose a method for the extraction of the tensor of exchange interactions in the superconducting regime as described by the Bogoliubov-de Gennes equations. Finally, with our multi-orbital tight-binding code TITAN, we investigate a Mn (110) monolayer deposited on the Nb (110) surface and analyze the magnetic interactions of the superconducting and metallic phases.

–Work funded by Horizon 2020–ERC (CoG 681405–DYNASORE).

Invited Talk TT 16.3 Thu 10:45 H5

Magnetic adatom chains on superconducting $NbSe_2$ — Eva Liebhaber[1], Lisa M. Rütten[1], Gael Reecht[1], Jacob F. Steiner[2], Sebastian Rohlf[3], Kai Rossnagel[3], Felix von Oppen[2], and •Katharina J. Franke[1] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Germany — [3]Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Germany

Magnetic adatom chains on superconducting substrates constitute a fascinating platform to study the interplay of quantum magnetism and superconductivity. Here, we investigate magnetic adatom chains in the dilute limit. This means that the atoms are sufficiently far spaced that direct hybridization of their d orbitals is negligible, but close enough for sizeable substrate-mediated interactions. We build these chains from individual Fe atoms on a 2H-$NbSe_2$ substrate. Using scanning tunneling microscopy and spectroscopy we first characterize the exchange coupling between the magnetic adatoms and the superconductor by detecting their Yu-Shiba-Rusinov states within the superconducting energy gap. We then use the tip of the STM to assemble dimers, trimers and chains of these Fe atoms. In each step, we track the evolution of the Yu-Shiba-Rusinov states and identify magnetic interactions, hybridization and band formation.

TT 16.4 Thu 11:15 H5

Tuning the interaction between spins coupled to a superconductor on the atomic level — •Felix Küster[1], Ana M. Montero[2], Filipe S. M. Guimarães[2], Sascha Brinker[2], Samir Lounis[2], Stuart S. P. Parkin[1], and Paolo Sessi[1] — [1]Max Planck Institute of Microstructure Physics, Halle, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, Jülich, Germany

Magnetic impurities coupled to superconducting condensates induce sharp in-gap resonances, the so-called Yu-Shiba- Rusinov (YSR) states. By reducing the distance between impurities, YSR quasiparticles can interact, hybridize, and eventually form bands. Here, we scrutinize the behavior of 3d atoms coupled to niobium by scanning tunneling microscopy and spectroscopy. We demonstrate how the coupling between spins and a superconducting condensate hosting an anisotropic Fermi surface can be tuned by varying the direction and distance between the impurities. We verify the existence of long range coupling as well as the crossing through a quantum phase transition, providing a promising platform for the emergence of topological superconductivity.

Invited Talk TT 16.5 Thu 11:30 H5

Yu-Shiba-Rusinov states and ordering of magnetic Impurities near the boundary — •Jelena Klinovaja — University of Basel, Basel, Switzerland

In my talk, I will discuss properties of one and two magnetic impurities near the boundary of a one-dimensional nanowire in proximity to a conventional s-wave superconductor. We showed that the energies of the subgap states, supported by the magnetic impurities, are strongly affected by the boundary for distances less than the superconducting coherence length. When the impurity is moved towards the boundary, multiple quantum phase transitions periodically occur in which the parity of the superconducting condensate oscillates between even and odd. The magnetic ground-state configuration of two magnetic impurities depends not only on the distance between them, but also explicitly on their distance away from the boundary of the nanowire. As a consequence, the magnetic ground state can switch from ferromagnetic to antiferromagnetic while keeping the interimpurity distance unaltered by simultaneously moving both impurities away from the boundary.

[1] O. Deb, S. Hoffman, D. Loss, and J. Klinovaja, Phys. Rev. B 103, 165403 (2021). [2] H. Ding, Y. Hu, M. T. Randeria, S. Hoffman, O. Deb, J. Klinovaja, D. Loss, and A. Yazdani, Proc. Natl. Acad. Sci. USA 118, 14 (2021). [3] S. Hoffman, J. Klinovaja, T. Meng, and D. Loss, .Phys. Rev. B 92, 125422 (2015). [4] T. Meng, J. Klinovaja, S.

Hoffman, P. Simon, and D. Loss, Phys. Rev. B 92, 064503 (2015).

TT 16.6 Thu 12:00 H5

Temperature-Dependent Spin Transport and Current-Induced Torques in Superconductor-Ferromagnet Heterostructures — •Manuel Müller[1,2], Lukas Liensberger[1,2], Luis Flacke[1,2], Hans Huebl[1,2,3], Akashdeep Kamra[4], Wolfgang Belzig[5], Rudolf Gross[1,2,3], Mathias Weiler[1,2,6], and Matthias Althammer[1,2] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik- Department, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [4]Norwegian University of Science and Technology, Trondheim, Norway — [5]Physik-Department, Universität Konstanz, Konstanz, Germany — [6]Fachbereich Physik, TU Kaiserslautern, Kaiserslautern, Germany

Proximity effects at superconductor(SC)/ferromagnet(FM) interfaces provide novel functionality in superconducting spintronics. We investigate the injection of spin currents in NbN/permalloy (Py) heterostructures with and without a Pt spin sink layer. Spin currents are excited by broadband ferromagnetic resonance in the Py-layer coupled inductively to a coplanar waveguide and quantitative information on the spin current physics is obtained by measuring the complex microwave transmission as a function of temperature. Our findings, reveal the symmetry and strength of spin-to-charge current conversion in SC/FM heterostructures and provide guidance for future superconducting spintronics devices. Our results are published in Phys. Rev. Lett. **126**, 087201 (2021). We acknowledge financial support by the DFG.

Invited Talk TT 16.7 Thu 12:15 H5

Resonance from antiferromagnetic spin fluctuations for spin-triplet superconductivity in UTe2 — •Pengcheng Dai — Rice University

Superconductivity has its universal origin in the formation of bound (Cooper) pairs of electrons that can move through the lattice without resistance below the superconducting transition temperature Tc. While electron Cooper pairs in most superconductors form anti-parallel spin-singlets with total spin S = 0, they can also form parallel spin-triplet Cooper pairs with S = 1 and an odd parity wavefunction. Spin-triplet pairing is important because it can host topological states and Majorana fermions relevant for fault tolerant quantum computation. However, spin-triplet pairing is rare and has not been unambiguously identified in any solid state systems. Since spin-triplet pairing is usually mediated by ferromagnetic (FM) spin fluctuations, uranium based heavy-fermion UTe2, which has a Tc * 1.6 K, has been identified as a strong candidate for chiral spin-triplet topological superconductor near a FM instability. Here we use inelastic neutron scattering (INS) to show that superconductivity in UTe2 is coupled with a sharp magnetic excitation at the Brillouin zone (BZ) boundary near AF order, analogous to the resonance seen in other exotic superconductors. We find that the resonance in UTe2 occurs below Tc at an energy Er = 7.9kBTc. Since the resonance has only been found in spin-singlet superconductors near an AF instability, its discovery in UTe2 suggests that AF spin fluctuations can also induce spin-triplet pairing for superconductivity.

TT 17: Charge Density Wave Materials

Time: Thursday 10:00–11:00 Location: H6

TT 17.1 Thu 10:00 H6

Condensation signatures of photogenerated interlayer excitons in a van der Waals heterostack — •Johannes Figueiredo[1], Lukas Sigl[1], Florian Sigger[1], Jonas Kiemle[2], Ursula Wurstbauer[1], and Alexander Holleitner[1] — [1]Walter Schottky Institut, Technical University of Munich — [2]Institute of Physics, Westfälische Wilhelms-Universität Münster

Due to large exciton binding energies and long lifetimes, atomistic van der Waals heterostacks of TMDCs present an ideal platform for studying high-temperature condensation of excitons. At cryogenic temperatures, optically generated interlayer excitons in such heterostructures yield several signatures regarding the condensation of the photogenerated excitons. The transition into this state is consistent with the predicted critical condensation temperature above 10K. Our studies provide a first phase-diagram of the achieved quantum degenerate interlayer exciton ensemble. [1]

[1] L. Sigl *et. al*, Phys. Rev. Research 2, 042044(R) (2020)

TT 17.2 Thu 10:15 H6

Doping fingerprints of spin and lattice fluctuations in moiré superlattice systems — •Niklas Witt[1], José Pizarro[1], Takuya Nomoto[2], Ryotaro Arita[2], and Tim Wehling[1] — [1]Universität Bremen — [2]University of Tokyo

Twisted van der Waals materials open up novel avenues to control electronic correlation and topological effects. These systems contain the unprecedented possibility to precisely tune strong correlations, topology, magnetism, nematicity, and superconductivity with an external non-invasive electrostatic doping. By doing so, rich phase diagrams featuring an interplay of different states of correlated quantum matter can be unveiled. The nature of the superconducting order presents a recurring overarching open question in this context.

In this work, we quantitatively assess the case of spin-fluctuation-mediated pairing for Γ-valley twisted transition metal dichalcogenide homobilayers. We construct a low-energy honeycomb model on which basis we self-consistently and dynamically calculate a doping dependent phase diagram for the superconducting transition temperature T_c. A superconducting dome emerges with a maximal $T_c \approx 0.1$-1 K depending on twist angle. We qualitatively compare our results with conventional phonon-mediated superconductivity and discern clear fingerprints which are detectable in doping-dependent measurements of the superconducting transition temperature, providing direct access to probing the superconducting pairing mechanism in twisted Van der Waals materials.

TT 17.3 Thu 10:30 H6

Electronic transformations in the semi-metallic transitional oxide Mo_8O_{23} — Venera Nasretdinova[1], •Yaroslav Gerasimenko[2,3], Jernej Mravlje[3], Gianmarco Gatti[4], Petra Sutar[3], Damjan Svetin[3], Anton Meden[5], Viktor Kabanov[3], Alexander Kuntsevich[6,7], Marco Grioni[4], and Dragan Mihailovic[1,3,5] — [1]CENN Nanocenter, Ljubljana, Slovenia — [2]University of Regensburg, Germany — [3]JSI, Ljubljana, Slovenia — [4]EPFL, Lausanne, Switzerland — [5]University of Ljubljana, Slovenia — [6]LPI RAS, Moscow, Russia — [7]HSE, Moscow, Russia

Mo_8O_{23} is a low-dimensional stoichiometric transitional metal oxide from MoO_{3-x} family. Its room-temperature phase associated with charge density wave (CDW) is accompanied by non-monotonic resistivity at low temperatures well below structural transitions. Using tunneling and angle-resolved spectroscopy, transport measurements and density functional calculations we reveal electronic transformations leading to a multi-band correlated ground state [1,2]. We observe the metal-to-insulator transition at 343K in resistivity, consistent with CDW onset. At low temperatures, the picture with the only CDW order parameter is broken by the onset of the correlated ground state visible both in transport and spectroscopic probes. Spatially-resolved tunneling spectroscopy studies reveal the emergent electronic texture. We discuss the possible origins of the electronic order that emerge in the absence of any structural or magnetic transitions [3].

[1] V. Nasretdinova et al. PRB 99, 085101

[2] V. Nasretdinova et al., Sci.Rep. 9, 15959 (2019)

[3] V. Nasretdinova et al., in preparation

TT 17.4 Thu 10:45 H6

Field tuning beyond the heat death of a charge-density-wave chain — •Manuel Weber[1,2] and James Freericks[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Department of Physics, Georgetown University, Washington, DC 20057, USA

Time-dependent driving of quantum systems has emerged as a powerful tool to engineer exotic phases far from thermal equilibrium; when the drive is periodic this is called Floquet engineering. The presence of many-body interactions can lead to runaway heating, so that generic systems are believed to heat up until they reach a featureless infinite-temperature state. Finding mechanisms to slow down or even avoid this heat death is a major goal—one such mechanism is to drive toward an even distribution of electrons in momentum space. Here we show how such a mechanism avoids the heat death for a charge-density-wave chain in a strong dc electric field; minibands with nontrivial distribution functions develop as the current is prematurely driven to zero. We also show how the field strength tunes between positive, negative, or close-to-infinite effective temperatures for each miniband. These results suggest that nontrivial metastable distribution functions should be realized in the prethermal regime of quantum systems coupled to slow bosonic modes.

TT 18: Frustrated Magnets

Time: Thursday 10:00–12:45 Location: H7

TT 18.1 Thu 10:00 H7

Magnon Crystallization in the Kagome Lattice Antiferromagnet — •Jürgen Schnack[1], Jörg Schulenburg[2], Andreas Honecker[3], and Johannes Richter[4] — [1]Fakultät für Physik, Universität Bielefeld, Postfach 100131, D-33501 Bielefeld, Germany — [2]Universitätsrechenzentrum, Universität Magdeburg, D-39016 Magdeburg, Germany — [3]Laboratoire de Physique Theorique et Modelisation, CNRS UMR 8089, CY Cergy Paris Universite, F-95302 Cergy-Pontoise Cedex, France — [4]Institut für Physik, Universität Magdeburg, P.O. Box 4120, D-39016 Magdeburg, Germany & Max-Planck-Institut für Physik Komplexer Systeme, Nöthnitzer Straße 38, D-01187 Dresden, Germany

We present numerical evidence for the crystallization of magnons below the saturation field at nonzero temperatures for the highly frustrated spin-half kagome Heisenberg antiferromagnet [Phys. Rev. Lett. 125, 117207 (2020)]. This phenomenon can be traced back to the existence of independent localized magnons or, equivalently, flatband multimagnon states. We present a loop-gas description of these localized magnons and a phase diagram of this transition, thus providing information for which magnetic fields and temperatures magnon crystallization can be observed experimentally. The emergence of a finite-temperature continuous transition to a magnon crystal is expected to be generic for spin models in dimension D $>$ 1 where flatband multimagnon ground states break translational symmetry.

TT 18.2 Thu 10:15 H7

Coexistence of static and dynamic spins in the new Kitaev iridate β-ZnIrO$_3$ — •Aleksandr Zubtsovskii and Alexander A. Tsirlin — EP VI, EKM, University of Augsburg, Germany

The three-dimensional Kitaev iridate β-Li$_2$IrO$_3$ shows complex magnetic behavior caused by the exchange anisotropy and frustration, and serves as a suitable ground to seek new materials with spin-liquid physics. Here, we report the detailed study of magnetic properties in the new Kitaev compound, β-ZnIrO$_3$, prepared by the low-temperature topotactic ion exchange reaction. The crystal structure characterized by x-ray and neutron diffraction as well as high-resolution electron microscopy exhibits symmetry lowering with respect to the parent β-Li$_2$IrO$_3$, but no structural disorder. Magnetic behavior is studied using magnetization and heat capacity measurements as well as μSR. The results indicate spin freezing below $T_f \sim 5$ K and a broad fluctuating regime that extends up to 40 K.

TT 18.3 Thu 10:30 H7

Spin-orbit coupled Mott insulator, Sr$_2$IrO$_4$: spin and charge orders — •Mehdi Biderang[1], Alireza Akbari[2], and Jesko Sirker[1] — [1]Department of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2 — [2]Max Planck Institute for the Chemical Physics of Solids, D-01187 Dresden, Germany

An antisymmetric spin-orbit coupling of a two-dimensional single-band Hubbard Hamiltonian is investigated. We propose that this is the most basic paradigm for understanding the electrical characteristics of locally noncentrosymmetric transition metal (TM) oxides like Sr$_2$IrO$_4$. Based on exact diagonalizations of small clusters and the random-phase approximation, we study the correlation effects on charge and magnetic order as a function of doping and of the TM-oxygen-TM bond angle. We see dominating commensurate in-plane antiferromagnetic fluctuations for low doping and small angles, whereas ferromagnetic fluctuations dominate for larger angles. Moderately strong nearest-neighbor Hubbard interactions can also stabilize a charge density wave order. We find good qualitative agreement between the dispersion of magnetic excitations in the hole-doped scenario and resonant inelastic x-ray scattering measurements.

TT 18.4 Thu 10:45 H7

Two-triplon excitations in frustrated bilayer systems — •Erik Wagner and Wolfram Brenig — Institute for Theoretical Physics, Technical University Braunschweig, Braunschweig, Germany

We study the magnetism of frustrated bilayer spin models. Starting from the limit of decoupled dimers we use the perturbative continuous unitary transformation (pCUT), based on the flow equation method, to perform series expansion in order to analyze the spectrum, up to the two-triplon excitations. First we apply this method to the Kitaev-Heisenberg bilayer, consisting of two honeycomb Kitaev spin-models with anisotropic intralayer Ising-exchange $J_{x,y,z}$, coupled by additional interlayer Heisenberg exchange J. We evaluate the groundstate energy and the one particle dispersion up to 9th order in $J_{x,y,z}$ as well as the two-particle interactions and spectrum up to 6th order [1]. We detail the presence of (anti-)bound two-particle states and analyze their wavefunctions. Additionally we discuss the impact of two-particle interactions on the magnetic Raman response of the Kitaev-Heisenberg bilayer. Extensions of our approach to other frustrated bilayers will be considered, focusing on the $SU(2)$ invariant J-J_1-J_2-Heisenberg square-lattice bilayer and including calculations up to 7th and 4th order in $J_{1,2}$ for one- and two-particle matrix elements.

[1] E. Wagner, W. Brenig, arXiv:2103.13402

15 min. break.

TT 18.5 Thu 11:15 H7

Anisotropy of the magnetoelastic coupling investigated in the Kitaev material RuCl$_3$ — •Vilmos Kocsis[1], David A. S. Kaib[2], Kira Riedl[2], Sebastian Gass[1], Paula Lampen-Kelley[3,4], David G. Mandrus[3,4], Stephen E. Nagler[4], Nicolas P. Rodriguez[1], Kornelius Nielsch[1], Roser Valenti[2], Bernd Büchner[1], and Anja U. B. Wolter[1] — [1]IFW-Dresden, Dresden, Germany — [2]Goethe-Universität Frankfurt, Frankfurt, Germany — [3]University of Tennessee, Knoxville, USA — [4]Oak Ridge National Laboratory, Oak Ridge, USA

The Kitaev material α-RuCl$_3$ is among the most promising candidates to host a quantum spin-liquid state. Recent investigations have revealed the importance of the magnetoelastic coupling and the magnetic anisotropy in α-RuCl$_3$. In this combined theoretical and experimental research we investigate the anisotropic magnetic and magnetoelastic properties for magnetic fields applied along the main crystallographic axes as well as for fields canted out of the honeycomb plane. We found that the magnetostriction anisotropy is unusually large compared to the anisotropy of the magnetization, which is related to the strong magnetoelastic $\widetilde{\Gamma}'$-type coupling in our *ab-initio* derived model. We observed large, non-symmetric anisotropy in the magnetic and magnetoelastic properties for magnetic fields canted out of the honeycomb *ab*-plane in opposite directions, namely for fields canted towards the $+c^*$ or $-c^*$ axes, respectively). The observed directional anisotropy is related to the uniformly aligned Cl$_6$ octahedra around the magnetic ion Ru^{3+}.

TT 18.6 Thu 11:30 H7

Evidence for kagome intrinsic excitations in the thermal conductivity of herbertsmithite — •Ralf Claus[1], Jan Bruin[1], Yosuke Matsumoto[1], Masahiko Isobe[1], Jürgen Nuss[1], and Hidenori Takagi[1,2,3] — [1]Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, D-70569 Stuttgart, Germany — [2]Department of Physics, The University of Tokyo, Bunkyo-ku,Tokyo 133-0022, Japan — [3]Institute for Functional Matter and Quantum Technologies,University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Quantum spin liquids (QSLs) are a novel state of matter that may host exotic excitations like itinerant charge-neutral spin-1/2 quasiparticles (spinons). One prominent candidate for a QSL ground state is the spin-1/2 Heisenberg antiferromagnet on the kagome lattice. Herbertsmithite ($ZnCu_3(OH)_6C_{l2}$) provides a perfect realization of this model. However, despite intense theoretical and experimental efforts the nature of its ground state remains under debate. An important open question concerns the existence of an excitation gap.

To address this issue, we performed thermal transport measurements on herbertsmithite single crystals down to 80 mK. Thermal conductivity (k) only captures mobile excitations in the material and is therefore a powerful tool to detect low-lying (gapless) spinons. In our measurements, we confirmed the absence of a finite k/T(spinon Fermi surface) term but additionally observed an unusual field dependence. By carefully comparing in- and out-of-plane heat flow, we were able to identify kagome intrinsic excitations down to lowest temperature.

TT 18.7 Thu 11:45 H7

Interplay of magnetism and dimerization in pressurized Kitaev compound β-Li_2IrO_3 — •Bin Shen, Anton Jesche, Maximilian Seidler, Friedrich Freund, Philipp Gegenwart, and Alexander A. Tsirlin — EP VI, EKM, University of Augsburg, Germany

Quantum spin liquids in a Kitaev honeycomb model, characterized by their quantum entanglement and fractionalized spin excitations, are subject to extensive studies recently. Here, we present magnetization measurements under pressure for β-Li_2IrO_3, the Kitaev material with the putative pressure-induced spin-liquid state, and construct the temperature-pressure phase diagram. A delicate interplay between magnetism and dimerization is revealed. β-Li_2IrO_3 undergoes incommensurate magnetic ordering at $T_N = 38\,K$ at ambient pressure. Upon applying hydrostatic pressure, T_N is almost pressure-independent before the transition abruptly disappears at around 1.5 GPa. At around 1.4 GPa, a signature of structural dimerization seen as a small step in the magnetic susceptibility appears at $T_d \approx 120$ K and shifts to higher temperatures upon further compression. Intriguingly, a low-temperature Curie-like upturn with the effective moment of about $0.7\,\mu_B$ is still observed. Using ab initio calculations, we interpret these results as the formation of a partially dimerized state that evades long-range magnetic order but features a fraction of magnetic Ir^{4+} sites.

Work supported by the German Research Foundation through the Sino-German Cooperation Group on Emergent Correlated Matter.

TT 18.8 Thu 12:00 H7

Thermal Transport of a Co-based candidate Kitaev quantum spin liquid (kQSL) material $Na_2Co_2TeO_6$ — •Xiaochen Hong[1,2], Matthias Gillig[1], Richard Hentrich[1], Weiliang Yao[3], Vilmos Kocsis[1], Arthur Witte[1,4], Tino Schreiner[1], Danny Baumann[1], Nicolás Pérez[1], Anja Wolter[1], Yuan Li[3], Bernd Büchner[1,4], and Christian Hess[1,2] — [1]IFW-Dresden, Germany — [2]Bergische Universität Wuppertal, Germany — [3]Peking University, China — [4]TU Dresden, Germany

Motivated by recent theoretical predications that kQSL states can be realized in certain $3d$ transition metal based materials, we studied the thermal transport properties of $Na_2Co_2TeO_6$ single crystals in a wide field-temperature parameter space, up to 16 T and down to 50 mK. We found that phonons, which are strongly scattered by magnetic excitations, are responsible for thermal transport in $Na_2Co_2TeO_6$. By analyzing the field-temperature dependence of the magneto-phonon scattering, we found major similarities between $Na_2Co_2TeO_6$ and the leading kQSL candidate α-$RuCl_3$, supporting theoretical proposals. Besides, we discovered highly anisotropic field effect, signatures of multiple field-induced transitions, and novel oscillation-like thermal transport features. Our findings encourage more studies on $Na_2Co_2TeO_6$, as a promising kQSL material and an exotic quantum magnet.

TT 18.9 Thu 12:15 H7

Spin liquid and ferroelectricity close to a quantum critical point in $PbCuTe_2O_6$ — •Christian Thurn[1], Paul Eibisch[1], Arif Ata[1], Maximilian Winkler[2], Peter Lunkenheimer[2], István Kézsmárki[2], Ulrich Tutsch[1], Yohei Saito[1], Steffi Hartmann[1], Jan Zimmermann[1], Abanoub R. N. Hanna[3,4], A. T. M. Nazmul Islam[4], Shravani Chillal[4], Bella Lake[3,4], Bernd Wolf[1], and Michael Lang[1] — [1]PI, Goethe University Frankfurt — [2]EP V, University Augsburg — [3]IFKP, TU Berlin — [4]HZ Berlin

Geometrical frustration among interacting spins combined with strong quantum fluctuations destabilize long-range magnetic order in favor of more exotic states such as spin liquids (SL). While in quasi-two-dimensional (quasi-2D) systems a number of SL candidates were found, in 3D the situation is less favorable due to reduced quantum fluctuations and more relevant competing states. Here we report studies of thermodynamic, magnetic and dielectric properties on single crystalline and pressed-powder samples of $PbCuTe_2O_6$, a candidate for a 3D frustrated quantum spin liquid (QSL) [1-3] featuring a hyperkagome lattice. Whereas the low-T properties of the powder are consistent with the proposed QSL state [1-3], a more exotic behaviour is found for the single crystals: they show ferroelectric order at $T_{FE} \approx 1\,K$, accompanied by strong lattice distortions, and a modified magnetic response – still consistent with a QSL – but with clear indications for quantum critical behaviour.

[1] Koteswararao *et al.*, PRB **90**, 035141 (2014)
[2] Khuntia *et al.*, PRL **116**, 107203 (2016)
[3] Chillal *et al.*, Nat. Commun. **11**, 2348 (2020)

TT 18.10 Thu 12:30 H7

NMR and magnetization investigations of the field-induced order in the frustrated triangular-lattice compound $NaYbSe_2$ — •S. Luther[1,2], K. M. Ranjith[3], T. Reimann[1], Ph. Schlender[4], B. Schmidt[3], J. Sichelschmidt[3], H. Yasuoka[3], J. Wosnitza[1,2], T. Doert[4], M. Baenitz[3], and H. Kühne[1] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]MPI for Chemical Physics of Solids, Dresden, Germany — [4]Faculty of Chemistry and Food Chemistry, TU Dresden, Germany

The Yb-based delafossite $NaYbSe_2$ is a triangular-lattice antiferromagnet with space group $R\bar{3}m$. In this compound, spin-orbit coupling leads to a pronounced magnetic anisotropy. The absence of magnetic long-range order at zero field is suggestive for a quantum spin-liquid ground state. From specific-heat and magnetization experiments, magnetically ordered states were observed for $H \perp c$ and $H \parallel c$ exceeding 2 and 9 T, respectively. ^{23}Na ($I = 3/2$) NMR probes the microscopic details of the field-induced magnetic structure. Measurements of the $1/T_1$-relaxation rate are consistent with the specific-heat data. At $H \perp c$ = 5 T, the magnetization indicates an up-up-down spin arrangement with according asymmetric broadening of the NMR spectra. At $H \parallel c$ = 16 T, an umbrella-type configuration of the magnetic moments is predicted, in agreement with a symmetric broadening of the NMR spectra. Low-field measurements reveal a continuous increase of the $1/T_1$-relaxation rate and spectral broadening without any signature of long-range order down to 0.3 K.

TT 19: Unconventional Superconductors

Time: Thursday 11:15–12:45 Location: H6

TT 19.1 Thu 11:15 H6

Characterization and spectroscopy of a new non-centrosymmetric superconductor — •Alfredo Spuri, Angelo Di Bernardo, and Elke Scheer — Universität Konstanz

Superconductor with a lack of inversion symmetry in their crystal structure have recently been proposed as systems hosting an unconventional and other topologically nontrivial superconducting states, which could pave their application for the fabrication of novel devices for superconducting spintronics and quantum computing. Moved by these motivations, we have investigated the transport and spectroscopic properties of the non-centrosymmetric superconductor Nb0.18Re0.82 down to the 2D limit. Hall transport measurements in the normal state and tunnelling spectroscopic experiments reveal the emergence of a complex physical behaviour, which suggests the existence of a superconducting order parameter with unconventional properties.

TT 19.2 Thu 11:30 H6

Spatially intertwined superconductivity and charge order in 1T-TaSSe revealed by scanning tunnelling spectroscopy — •Yaroslav Gerasimenko[1,2], Marion van Midden[2], Erik Zupanic[2], Petra Sutar[2], Zvonko Jaglicic[3], and Dragan Mihailovic[2,3] — [1]University of Regensubrg, Regensburg, Germany — [2]Jozef Stefan Institute, Ljubljana, Slovenia — [3]Univeristy of Ljubljana, Ljubljana, Slovenia

The interplay of different emergent phenomena - superconductivity (SC) and domain formation - appearing on different spatial and energy scales are investigated using high-resolution scanning tunnelling spectroscopy in the prototypical transition metal dichalcogenide superconductor 1T-TaSSe single crystals ($T_{SC} = 3.5\,\mathrm{K}$) at temperatures from 1 to 20 K. Our major observation is that while the SC gap size smoothly varies on the scale of $\lesssim 10\,\mathrm{nm}$, its spatial distribution is not correlated to the domain structure. On the other hand, there is statistically significant correlation of the SC gap Δ_{SC} with spectral weight of the narrow band at the Fermi level formed from the same Ta $5d$ orbitals as the Mott-Hubbard band. We show that the narrow band follows the evolution of Hubbard bands in space, proving unambiguously its relation to the charge order. The correlations between the two suggest a non-trivial link between rapidly spatially varying charge order and superconductivity common in many quantum materials, and high-temperature superconductors in particular.

TT 19.3 Thu 11:45 H6

Angular dependence of the superconductivity in $CeRh_2As_2$ — •Javier Landaeta[1], Pavlo Khanenko[1], Jacinta Banda[1], Ilya Sheikin[2], Sanu Mishra[2], Seunghyun Khim[1], Manuel Brando[1], Christoph Geibel[1], and Elena Hassinger[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Univ. Grenoble Alpes, CNRS, LNCMI EMFL, F-38042 Grenoble, France

$CeRh_2As_2$ is an unconventional superconductor with multiple superconducting phases. When $\mu_0 H \parallel c$, this material shows a field-induced transition from a low-field superconducting state SC1 to a high-field SC2 with critical field $H_{c2} = 14$ T and $T_c = 0.26$ K. For $\mu_0 H \parallel ab$, only the SC1 with $H_{c2} = 2$ T is observed. The phase-diagrams and their anisotropy might be explained by the influence of Rashba-spin-orbit coupling at the Ce sites where the inversion symmetry is broken locally. Above T_c, a possibly quadrupolar phase is present at $T_0 \approx 0.4$ K, whose influence on the superconducting state remains unknown. Here, we present a comprehensive study of the angular dependence of the upper critical fields and T_0 using low temperature magnetic ac susceptibility, specific heat and torque in single crystalline $CeRh_2As_2$. The SC2 state is strongly suppressed when rotating the magnetic field away from the c-axis and disappears for an angle of 35°. We find that the H_{c2} of SC2 for angles departing from the c axis is attained when the in-plane component of the field reaches the in-plane Pauli limit. This result corroborates idea that the field-induced state SC2 is an odd-parity state with a d-vector in the plane in $CeRh_2As_2$.

TT 19.4 Thu 12:00 H6

Twisted Superconductivity in the high magnetic field phase of $CeRh_2As_2$ — •Aline Ramires[1] and David Möckli[2] — [1]Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland — [2]Instituto de Física, Universidade Federal do Rio Grande do Sul, 91501-970 Porto Alegre, Brazil

$CeRh_2As_2$, a locally noncentrosymmetric heavy fermion material, was recently reported to host a remarkable magnetic field versus temperature phase diagram with two superconducting phases and upper critical fields much above the Pauli limit [1]. In this material, the two inequivalent Ce sites per unit cell, related by inversion symmetry, introduce a sublattice structure corresponding to an extra internal degree of freedom. In this talk, I briefly review some mechanisms that allow for Pauli limit violation and discuss what properties of the normal state are key for the development of a superconducting state robust against magnetic fields. I discuss intra-sublattice and inter-sublattice pairing scenarios and how we can construct superconducting states that violate the Pauli limit by twisting the most stable superconducting state with respect to the internal sublattice degree of freedom [2]. I will also comment on ongoing work that highlights the role of normal state electronic structure parameters, as well as effects of impurities, and subleading instabilities in the phase diagram of this material [3].

[1] S. Khim *et al.*, arXiv:2101.09522 (2021)
[2] D. Möckli and A. Ramires, Phys. Rev. Research **3**, 023204 (2021)
[3] D. Möckli and A. Ramires, arXiv:2107.09723 (2021)

TT 19.5 Thu 12:15 H6

Nematicity and checkerboard order in the surface layer of Sr_2RuO_4 — •Carolina A. Marques[1], Luke C. Rhodes[1], Rosalba Fittipaldi[2], Veronica Granata[3], Chi Ming Yim[1], Renato Buzio[2], Andrea Gerbi[2], Antonio Vecchione[2], Andreas W. Rost[1,4], and Peter Wahl[1] — [1]SUPA, School of Physics and Astronomy, University of St Andrews, UK. — [2]CNR-SPIN, Italy. — [3]Dipartimento di Fisica, Università di Salerno, Italy. — [4]Max-Planck-Institute for Solid State Research, Stuttgart, Germany.

Superconductivity in strongly correlated systems is often found near exotic electronic phases, such as antiferromagnetism and electronic nematicity. These phases can be highly sensitive to minor changes in the crystal structure, induced by doping or strain. In the unconventional superconductor Sr_2RuO_4, a 6° rotation of the RuO_6 octahedra at the surface seems to suppress its superconducting state and pushes a van Hove singularity below the Fermi energy. Using ultra-low temperature Scanning tunnelling microscopy, we study the low energy electronic properties of the reconstructed surface of Sr_2RuO_4[1]. Our measurements show clear signatures of C_4 symmetry breaking, together with the appearance of a checkerboard order, associated with a peak in the tunnelling spectrum, which splits in a magnetic field, revealing a charge nature. Tight binding calculations show that a nematic order parameter coexisting with a charge modulation reproduces the observed low energy density of states. Understanding the underlying physics at this surface provides a new platform to study the strongly correlated phases of Ruthenate materials.

[1] Adv. Mat. 2100593 (2021)

TT 19.6 Thu 12:30 H6

Quasiparticle Interference of the van-Hove singularity in Sr_2RuO_4 — •Andreas Kreisel[1], Carolina A. Marques[2], Luke C. Rhodes[2], Xiangru Kong[3], Tom Berlijn[3], Rosalba Fittipaldi[4], Veronica Granata[5], Antonio Vecchione[4], Peter Wahl[2], and Peter J. Hirschfeld[6] — [1]Institut für Theoretische Physik, Universität Leipzig — [2]SUPA, University of St Andrews,UK — [3]CNMS, Oak Ridge National Laboratory, USA — [4]CNR-SPIN, UOS Salerno, Italy — [5]Dipartimento di Fisica, Università di Salerno, Italy — [6]Department of Physics, University of Florida, USA

The single-layered ruthenate Sr_2RuO_4 is one of the most enigmatic unconventional superconductors. While for many years it was thought to be the best candidate for a chiral p-wave superconducting ground state, desirable for topological quantum computations, recent experiments suggest a singlet state, ruling out the original p-wave scenario. The superconductivity as well as the properties of the multi-layered compounds of the ruthenate perovskites are strongly influenced by a van Hove singularity in proximity of the Fermi energy. Tiny structural distortions move the van Hove singularity across the Fermi energy with dramatic consequences for the physical properties. Here, we determine the electronic structure of the van Hove singularity in the surface layer of Sr_2RuO_4 by quasiparticle interference imaging. We trace its dispersion and demonstrate from a model calculation accounting for the full vacuum overlap of the wave functions that its detection is facilitated through the octahedral rotations in the surface layer.

TT 20: Quantum Dots and Wires (joint session HL/TT)

Time: Thursday 13:30–16:30 Location: H4

Invited Talk TT 20.1 Thu 13:30 H4

Telecom wavelength quantum dot-based single-photon sources for quantum technologies — •Anna Musial — Department of Experimental Physics, Faculty of Fundamental Problems of Technology, Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland

Important building blocks for quantum technology applications are non-classical light sources, in particular those emitting single photons on demand. Among pursued approaches to realize them semiconductor epitaxial quantum dots (QDs) stand out in terms of single-photon purity, compatibility with semiconductor technology including deterministic fabrication of photonic structures, integration into photonic circuits and fiber infrastructure as well as unprecedented possibilities of engineering their electronic structure and optical properties. The current status, recent developments and future prospects of the single-photon sources based on single GaAs-based and InP-based epitaxial QDs emitting in the telecommunication spectral range will be given. Reviewed aspects include thermal stability of emission, energies for efficient quasi-resonant excitation, optimization of photon extraction efficiency, approaches to maximize coupling to a single mode telecom fiber, single-photon emission purity as well as tests of a fully operational plug&play fiber-based single-photon source.

TT 20.2 Thu 14:00 H4

Electric-field induced tuning of electronic correlation in weakly confining quantum dots — Huiying Huang[1], Diana Csontosová[2,3], Santanu Manna[1], Yongheng Huo[4], Rinaldo Trotta[5], Armando Rastelli[1], and •Petr Klenovský[2,3] — [1]Johannes Kepler University Linz, Linz, Austria — [2]Masaryk University, Brno, Czech Republic — [3]Czech Metrology Institute, Brno, Czech Republic — [4]University of Science and Technology of China, Hefei, Anhui, China — [5]Sapienza University of Rome, Rome, Italy

We conduct a combined experimental and theoretical study of the quantum confined Stark effect in GaAs/AlGaAs quantum dots obtained with the local droplet etching method. In the experiment, we probe the permanent electric dipole and polarizability of neutral and positively charged excitons weakly confined in GaAs quantum dots by measuring their light emission under the influence of a variable electric field applied along the growth direction. Calculations based on the configuration-interaction method show excellent quantitative agreement with the experiment and allow us to elucidate the role of Coulomb interactions among the confined particles and – even more importantly – of electronic correlation effects on the Stark shifts. Moreover, we show how the electric field alters properties such as built-in dipole, binding energy, and heavy-light hole mixing of multiparticle complexes in weakly confining systems, underlining the deficiencies of commonly used models for the quantum confined Stark effect.

TT 20.3 Thu 14:15 H4

Towards deterministic generation of time-bin entangled photons from GaAs quantum dots — •Florian Kappe[1], Yusuf Karli[1], Vikas Remesh[1], Santanu Manna[2], Armando Rastelli[2], and Gregor Weihs[1] — [1]Institute for Experimental Physics, University of Innsbruck, Austria — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University of Linz, Austria

Semiconductor quantum dots are bright, on-demand single photon sources to realise quantum communication devices. We present our progress towards the deterministic generation of time-bin entangled photon states utilizing single GaAs/AlGaAs quantum dota as photon sources. Our scheme relies on the use of highly chirped picosecond laser pulses and an optically dark exciton state acting as a metastable state. The fidelity of the state preparation is supported by numerical simulations on the quantum dot dynamics. To demonstrate the effect of chirped excitation pulses on the quantum dot, we present an adiabatic-rapid-passage acting on a two-photon resonant transition to the neutral biexciton state. This scheme allows the implementation of a deterministic two-photon source insensitive to power fluctuations of the pump laser.

TT 20.4 Thu 14:30 H4

Quantum Efficiency and Oscillator Strength of InGaAs Quantum Dots for Single-Photon Sources emitting in the Telecommunication O-Band — •Jan Grosse[1], Paweł Mrowiński[1,2], Nicole Srocka[1], and Stephan Reitzenstein[1] — [1]Technische Universität Berlin, Institute for Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Laboratory for Optical Spectroscopy of Nanostructures, Wrocław University of Technology, Wybrzeze Wyspiańskiego 27, Wrocław, Poland

We demonstrate experimental results based on time-resolved photoluminescence spectroscopy to determine the oscillator strength and the internal quantum efficiency (IQE) of InGaAs quantum dots (QDs) capped by a strain-reducing layer [1] which have been used in single-photon sources (SPS) emitting in the telecom O-Band [2]. The oscillator strength and IQE are evaluated by determining the radiative and non-radiative decay rate under variation of the optical density of states at the position of the QD [3]. We measure a QD sample with different thicknesses of the capping layer realized by a controlled wet-chemical etching process. From numeric modelling the radiative and nonradiative decay rates dependence on the capping layer thickness, we determine an oscillator strength of 24.6 * 3.2 and a high IQE of about (85 * 10)% for the long-wavelength InGaAs QDs [4].

[1] J. Bloch et al., Appl. Phys. Lett. 75, 2199 (1999). [2] A. Musiał et al., Adv. Quantum Technol. 3, 2000018 (2020). [3] J. Johansen et al., Phys. Rev. B 77, 073303 (2008). [4] J. Große et al, arXiv:2106.05351 (2021).

TT 20.5 Thu 14:45 H4

Resonance fluorescence of single In(Ga)As quantum dots emitting in the telecom C-band — •Julius Fischer, Cornelius Nawrath, Hüseyin Vural, Richard Schaber, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Quantum dots represent a rapidly developing platform as sources of non-classical states of light for tackling quantum communication and computation tasks. Especially quantum dots emitting in the telecom C-band (1530nm-1565nm) are promising candidates due to the low absorption losses in the existent telecommunication fiber network.

In this study, we investigate In(Ga)As quantum dots emitting in the telecom C-band under resonant excitation to examine coherence properties and to investigate their single-photon purity as well as photon indistinguishability. Under strong resonant cw excitation, high-resolution fluorescence spectra, namely the Mollow triplet, of a single quantum dot are investigated. These spectra, in combination with a comprehensive fitting procedure, are used as a method to quantitatively attribute decoherence processes and thus presenting an excellent method to provide important insights for future sample optimizations. In addition, under pulsed resonant excitation, the capability of emitting highly pure single photons ($g^{(2)}(0) = 0.023 \pm 0.019$) with a non-postselected indistinguishability of subsequently emitted photons of $V_{\mathrm{TPI}} = 0.144 \pm 0.015$ is demonstrated.

15 min. break

TT 20.6 Thu 15:15 H4

Evaluating a Plug&Play Telecom-Wavelength Single-Photon Source for Quantum Key Distribution — Timm Gao[1], •Lucas Rickert[1], Felix Urban[1], Jan Grosse[1], Nicole Srocka[1], Sven Rodt[1], Anna Musiał[2], Kinga Żołnacz[3], Paweł Mergo[4], Kamil Dybka[5], Wacław Urbańczyk[3], Grzegorz Sek[2], Sven Burger[6], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institute of Solid State Physics, Technical University Berlin, 10623 Berlin, Germany — [2]Department of Experimental Physics, Wrocław University of Science and Technology, 50-370 Wroclaw, Poland — [3]Department of Optics

and Photonics, Wroclaw University of Science and Technology, 50-370 Wrocław, Poland — [4]Institute of Chemical Sciences, Maria Curie Sklodowska University, 20-031 Lublin, Poland — [5]Fibrain Sp. z o.o., 36-062 Zaczernie, Poland — [6]Zuse Institute Berlin, 14195 Berlin, Germany

We report on quantum key distribution (QKD) tests using a 19-inch benchtop single-photon source at 1321 nm based on a fiber-pigtailed quantum dot (QD) integrated into a Stirling cryocooler. Emulating the polarization-encoded BB84 protocol, we achieve an antibunching of $g^{(2)}(0) = 0.10 \pm 0.01$, a raw key rate of up to 4.72 ± 0.13 kHz, and a maximum tolerable loss of 23.19 dB exploiting optimized temporal filters in the asymptotic limit [1]. Our study represents an important step forward in the development of fiber-based quantum-secured communication networks exploiting sub-Poissonian quantum light sources.

[1] T. Kupko et al., arXiv.2105.03473 (2021)

TT 20.7 Thu 15:30 H4

Emission and absorption of a radiative Auger transition — •Clemens Spinnler[1], Liang Zhai[1], Giang N. Nguyen[1], Julian Ritzmann[2], Andreas D. Wieck[2], Arne Ludwig[2], Alisa Javadi[1], Doris E. Reiter[4], Paweł Machnikowski[3], Richard J. Warburton[1], and Matthias C. Löbl[1] — [1]Department of Physics, University of Basel, Switzerland — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [3]Department of Theoretical Physics, Wrocław University of Science and Technology, Poland — [4]Institut für Festkörpertheorie, Universität Münster, Germany

In multi-electron systems, such as charged semiconductor quantum dots (QD), several electron-hole recombination processes can take place. Besides the well-known resonance fluorescence, Coulomb interactions can lead to radiative Auger processes (shake-up) where part of the recombination energy is transferred to another electron. This Auger electron is left in an excited state and the emitted photon is correspondingly red-shifted.

We report the observation of emission and absorption of a radiative Auger transition from a negatively charged QD. By applying quantum optics techniques to the Auger emission we get insight into single-electron dynamics. We show photon absorption via the radiative Auger transition by driving the QD in a Λ-configuration: while monitoring the resonance fluorescence a second laser is tuned in resonance with the radiative Auger transition. A fluorescence reduction of up to 70% is observed - proving optical driving of the radiative Auger transition.

TT 20.8 Thu 15:45 H4

Interfacing colloidal quantum dots with nanophotonic circuits for integrated single photon sources — •Tobias Spiekermann, Alexander Eich, Helge Gehring, Lisa Sommer, Julian Bankwitz, Wolfram Pernice, and Carsten Schuck — Institute of Physics, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Single photon sources are a key element for the realization of quantum communication, sensing and computing. While there exist several promising quantum emitter candidate systems, integration with nanophotonic networks in large numbers for wafer-scale quantum technologies has remained elusive. Here we show a lithographic technique that allows for interfacing nanophotonic waveguides with individual Colloidal Quantum Dots (CQD) from a solution applied across an entire chip [1]. We record the second order autocorrelation function to confirm single photon emission from CQDs into tantalum pentoxide (Ta_2O_5) waveguides that feature low intrinsic material fluorescence. Moreover, we demonstrate how iterative processing can be used to increase the yield of single CQDs with our technique. We further improve the photostability of CQDs positioned on a chip by subsequent site-passivation via atomic layer deposition of alumina (Al_2O_3). Our work paves the way for scalable integration of colloidal quantum dot single photon sources with photonic integrated circuits.

[1] Cherie R. Kagan, et al., Colloidal Quantum Dots as Platforms for Quantum Information Science, Chemical Reviews 121 (5), 3186-3233 (2021)

TT 20.9 Thu 16:00 H4

Electrical Characterisation of Te-doped InAs Nanowires grown by VS Molecular Beam Epitaxy — •Anton Faustmann, Pujitha Perla, Detlev Grützmacher, Mihail Lepsa und Thomas Schäpers — Peter-Grünberg-Institut PGI-9, FZ-Jülich, Jülich, Deutschland

InAs features high electron mobility and absence of a Schottky barrier at metal interfaces enabling ohmic contacts. In combination with large g-factor and high Rashba spin-orbit coupling this makes InAs nanowires a promising candidate for research of quantum effects. InAs nanowires with Te doping grown by molecular beam epitaxy were investigated in terms of their electrical transport properties at both room and cryogenic temperatures. The nanowires were grown in a catalyst-free vapour-solid process without using Au droplets. In contrast to Si, which shows amphoteric behaviour, Te acts as n-type dopant. It furthermore offers the possibility of an increased overall doping level. The Te doping concentration was found to affect both the morphology of the nanowires as well as electrical properties. The shape of the nanowires depends on Te uptake. Their intrinsic as well as contact resistances decrease considerably at increased doping level. Field-effect measurements using a global back gate show effect on the conductance, depending on the doping concentration. For higher doping no complete pinch-off was observable with conductance saturating at high negative gate voltages. Resistances were found to be only slightly increased at cryogenic temperatures.

TT 20.10 Thu 16:15 H4

Emission Time Statistics of a driven Single-Electron Transistor — •Johannes C. Bayer[1], Fredrik Brange[2], Adrian Schmidt[1], Timo Wagner[1], Christian Flindt[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Department of Applied Physics, Aalto University, Finland

Precisely controllable single particle sources are an essential part of different quantum technologies operating at fixed clock cycles. A high level of accuracy in the time domain thereby requires detailed understanding of the interplay between an external drive and the response of the single particle source [1,2]. We here present the influence of periodically modulated tunneling rates on the emission time statistics of electrons emitted from a single-electron transistor (SET) [3]. A highly sensitive charge detector allows to detect tunneling events in real-time. By ramping up the driving frequency from slower to faster than the electron tunneling rate, the response of the SET undergoes a transition from adiabatic to non-adiabatic dynamics. This transition is accompanied by significant changes in the emission time statistics, which can be visualized in the waiting time distribution and is well described by our detailed theory.

[1] T. Wagner, et. al., Nat. Phys. 15, 330-334 (2019).
[2] R. Hussein, et. al., Phys. Rev. Lett. 125, 206801 (2020).
[3] F. Brange, et. al., Sci. Adv. 7, eabe0793 (2021).

TT 21: Focus Session: Topological Kagome Metals

The peculiar nature of the kagome lattice known to give rise exotic quantum states. When mixed with the itinerant character of the carriers, theoretically, it is predicted to host dispersionless electronic flat bands along with the linearly dispersing Dirac bands allowing one to bring together the topologically nontrivial states and the electronic correlations that lie at the center of condensed matter physics due to their roles in variety of novel quantum phenomena, such as unconventional superconductivity, heavy-fermion physics, Mott insulator states, etc. Recently, the experimental efforts caught with the predictions and several compounds are proposed as promising kagome metals, where one can realize the peculiar kagome physics in the real-world environment.

Organizers: Ece Uykur and Martin Dressel (Stuttgart University)

Time: Thursday 13:30–16:00 Location: H7

Invited Talk TT 21.1 Thu 13:30 H7

A new class of charge density wave superconductors in the topological kagome metals AV_3Sb_5 (A=K, Rb, Cs) — •Stephen Wilson — Materials Department, University of California Santa Barbara

Kagome metals are compelling materials platforms for hosting electronic states that feature an interplay between topologically nontrivial electronic states and correlated electron phenomena. These two features can, for instance, arise from the Dirac points, flatbands, and saddle-points endemic to the kagome lattice type in simple tight-binding models. Recently in this field, the discovery of a new class of kagome metals of the form AV_3Sb_5 with A=K, Cs, or Rb has provided a unique setting for exploring the interplay between Z_2 electronic topology and intertwined charge density wave and superconducting orders. These metals realize a kagome lattice of nonmagnetic vanadium ions with an electron-filling that populates saddle-points and their corresponding van Hove singularities in the electronic density of states near the Fermi level. Nesting effects in this setting are predicted to stabilize a variety of unusual states, ranging from charge density wave order that breaks time reversal symmetry to unconventional superconductivity. Here I will present some of our recent work exploring the phase transitions and broken symmetries in these materials. Particular attention will be given to the nature of the charge density wave instability.

TT 21.2 Thu 14:00 H7

Kagome metals — •Ronny Thomale — Theoretische Physik I, Julius-Maximilians-Universität Würzburg

The recent discovery of AV_3Sb_5 (A=K,Rb,Cs) has uncovered an intriguing arena for exotic Fermi surface instabilities in kagome metals. Aside from charge density wave order, a multi-dome superconducting phase is found, with strong indications to be of unconventional origin. We find that the sublattice interference mechanism is necessary and sufficient to uncover the nature of unconventional particle-hole and particle-particle pairing in the V net kagome metals. We predict a Peierls-type charge density wave with finite relative angular momentum and orbital current formation. With regard to the possible nature of unconventional pairing, we find a rich phase diagram depending on the range of the screened electronic interactions, the multi-orbital content, and the location of multiple van Hove singularities with respect to the Fermi level. Combined, kagome metals open a new domain of unconventional electronic order, unfolding a plethora of fascinating experimental and theoretical investigations.

TT 21.3 Thu 14:15 H7

Kagome and non-kagome physics of AV_3Sb_5 — •Alexander A. Tsirlin — EP VI, EKM, University of Augsburg, Germany

Layered compounds AV_3Sb_5 (A = K, Rb, Cs) are non-magnetic kagome metals with an intricate coexistence of and competition between superconducting and charge-density-wave (CDW) instabilities. In this talk, I will present our recent study of these compounds via x-ray diffraction, density-functional calculations, and broadband optical spectroscopy, with a focus on delineating between the roles of vanadium kagome planes and Sb atoms that encompass these planes. The following aspects will be addressed: i) band saddle points in the vicinity of the Fermi level and their positions depending on the A atom; ii) possible structures of the CDW state; iii) electronic and structural mechanisms of stabilizing the CDW; iv) evolution of crystal and electronic structures under pressure where re-entrant superconductivity has been observed. I will argue that both CDW formation in and pressure evolution of AV_3Sb_5 are strongly influenced by the Sb atoms that should be deemed an integral part of these kagome metals.

15. min. break

TT 21.4 Thu 14:45 H7

Study on the Magnetic Weyl Semimetal Phase in Kagome Lattice, $Co_3Sn_2S_2$ — •Defa Liu — Max Planck Insititute of Microstructure Physics

Materials with kagome lattice attract lots of investigations recently as they can realize many exotic phases and properties, such as the existence of flat band,superconductivity, CDW order, topological Dirac semimetal and Weyl semimetal phases, which can provide an ideal platform to study the interplay between them. Among the kagome materials, the ferromagnetic $Co_3Sn_2S_2$ has many exotic physical properties, such as the large anomalous Hall effect (AHE) and the anomalous Nernst effect (ANE). And also $Co_3Sn_2S_2$ is the first experimentally confirmed magnetic Weyl semimetal. In this talk, I will introduce how to use the angle-resolved photoemission spectroscopy (ARPES) to confirm the magnetic Weyl semimetal phase in $Co_3Sn_2S_2$, including the observation of the surface Fermi arcs and bulk Weyl point [1], the observation of the spin-orbit coupling (SOC) effect [2], and the observation of the topological phase transition in $Co_3Sn_2S_2$ [3]. These results not only can help to understand the formation mechanism of the Weyl semiemtal phase and the large anomalous Hall effect (AHE) and the anomalous Nernst effect (ANE) in $Co_3Sn_2S_2$, but also provide insights into the interplay between the magnetism and the topology.

[1] D.F. Liu et al., Science 365, 1282-1285 (2019)
[2] D.F. Liu et al., arXiv: 2103.08113
[3] D.F. Liu et al., arXiv: 2106.03229

TT 21.5 Thu 15:15 H7

Optical investigations of *Re*Mn_6Sn_6 kagome metals — •Maxim Wenzel[1], Olga Iakutkina[1], Hechang Lei[2], Martin Dressel[1], and Ece Uykur[1] — [1]1. Physikalisches Institut, Universität Stuttgart, D-70569 Stuttgart, Germany — [2]Department of Physics, Renmin University of China, 100872 Beijing, China

Magnetic kagome metals became model compounds for exploring the interplay between strong electronic correlations and magnetism along with topologically non-trivial states. Consisting of magnetic kagome planes along with the itinerant carriers, they ought to possess Dirac Fermions, flat bands and saddle points in the vicinity of the Fermi energy, E_F. The rare earth kagome metal series, $Re$$Mn_6Sn_6$ (Re = Gd, Tb, Y) opens a new way for further investigations of the influence of magnetism on the electronic properties. While the crystal structure does not differ significantly, the underlying magnetic structure strongly depends on the rare earth element separating the Mn-kagome layers. Here, we report temperature-dependent optical spectroscopy study on series of $Re$$Mn_6Sn_6$ compounds in a broad frequency range of 50 - 18000 cm^{-1} down to T = 10 K. The optical signatures of the strongly correlated flat bands and the Dirac fermions are comparatively discussed.

TT 21.6 Thu 15:30 H7

Polarization dependent localization in layered kagome metal FeSn — •Ananya Biswas[1], Frederik Bolle[1], Olga Iakutkina[1], Hechang Lei[2], Yoshichika Onukio[3], Martin Dressel[1], and Ece Uykur[1] — [1]1. Physikalisches Institut, Universität Stuttgart, D-70569

Stuttgart, Germany — [2]Department of Physics, Renmin University of China, 100872 Beijing, China — [3]Faculty of Science, University of Ryukyus, Japan

The roots of coexistence of Dirac bands and flat bands (from extended Hubbard Model) in kagome metals holds immense significance to study correlated electron systems. Antiferromagnetic FeSn is an ideal 2D kagome lattice having its Néel temperature T_N=370K. Moments of Fe atoms are ferromagnetically ordered within the Fe-Sn kagome planes, which are separated by Sn layers along c direction where each layer is coupled antiferromagtically to the adjacent kagome planes. Thus, FeSn provides ideal platform of polarization dependent investigation based on isolated and spatially decoupled kagome planes of 2D kagome network in bulk crystals. We investigated polarization effect of low energy dynamics in FeSn through infrared spectroscopy down to 10K. Results show two distinct carriers along kagome plane, which can be realized by Drude like free carrier contribution and a pronounced localization peak. Furthermore, a more coherent transport across kagome plane is reflected in our polarization dependent optical studies.

TT 21.7 Thu 15:45 H7

Nature of unconventional pairing in the kagome superconductors AV_3Sb_5 — •Xianxin Wu[1], Tilman Schwemmer[2], Tobias Müller[2], Armando Consiglio[2], Giorgio Sangiovanni[2], Domenico Di Sante[3], Yasir Iqbal[4], Werner Hanke[2], Andreas P. Schnyder[1], M. Michael Denner[5], Mark H. Fischer[5], Titus Neupert[5], and Ronny Thomale[2] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany — [2]University of Würzburg, Würzburg, Germany — [3]University of Bologna, Bologna, Italy — [4]Indian Institute of Technology Madras, Chennai, India — [5]University of Zurich, Zurich, Switzerland

The recent discovery of AV_3Sb_5 (A=K,Rb,Cs) has uncovered an intriguing arena for exotic Fermi surface instabilities in a kagome metal. Among them, superconductivity is found in the vicinity of multiple van Hove singularities, exhibiting indications of unconventional pairing. We show that the sublattice interference mechanism is central to understanding the formation of superconductivity in a kagome metal. Starting from an appropriately chosen minimal tight-binding model with multiple van Hove singularities close to the Fermi level for AV_3Sb_5, we provide a random phase approximation analysis of superconducting instabilities. Non-local Coulomb repulsion, the sublattice profile of the van Hove bands, and the interaction strength turn out to be the crucial parameters to determine the preferred pairing symmetry. Implications for potentially topological surface states are discussed, along with a proposal for additional measurements to pin down the nature of superconductivity in AV_3Sb_5.

TT 22: Poster Session: Disordered and Granular Superconductors: Fundamentals and Applications in Quantum Technology

Time: Thursday 13:30–15:30 Location: P

TT 22.1 Thu 13:30 P

Superinsulators: "localization" and granularity without disorder — •cristina diamantini[1] and carlo trugenberger[2] — [1]Department of Physics and Geology, University of Perugia, via Pascoli snc, Perugia, Italy — [2]SwissScientific Technologies SA, rue du Rhone 59, Geneva, Switzerland

It is often believed that suppression of transport in condensed matter systems requires many-body localization (MBL) by strong disorder. There is by now, however a vast body of literature showing that this is not the case: MBL-like phenomena can arise in absence of disorder by confinement, the phenomenon preventing quarks to "exit" from protons. I will discuss the example of the superinsulators, a new state of matter where condensation of magnetic monopole instantons generates an "endogenous emergent disorder" leading to an infinite resistance (even at finite temperatures) by the confinement of electric charge, Cooper pairs playing the role of quarks. The granularity of these materials around the superconductor-to-superinsulator transition is also emergent, due to the competition of two quantum phase transitions and is not due to disorder. I will present recent experimental evidence that rules out disorder-driven MBL as a cause of the infinite resistance, while confirming its endogenous instanton origin.

TT 22.2 Thu 13:30 P

Collective excitations in weakly-coupled disordered superconductors — •Bo Fan[1], Abhisek Samanta[2], and Antonio Miguel Garcia-Garcia[1] — [1]Shanghai Center for Complex Physics, School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China — [2]Physics Department, Technion, Haifa 32000, Israel

Isolated islands in two-dimensional strongly-disordered and strongly-coupled superconductors become optically active inducing sub-gap collective excitations in the ac conductivity. Here, we investigate the fate of these excitations as a function of the disorder strength in the experimentally relevant case of weak electron-phonon coupling. An explicit calculation of the ac conductivity, that includes vertex corrections to restore gauge symmetry, reveals the existence of collective sub-gap excitations, related to phase fluctuations and therefore identified as the Goldstone modes, for intermediate to strong disorder. As disorder increases, the shape of the sub-gap excitation transits from peaked close to the spectral gap to a broader distribution reaching much smaller frequencies. Phase-coherence still holds in part of this disorder regime. The requirement to observe sub-gap excitations is not the existence of isolated islands acting as nano-antennas but rather the combination of a sufficiently inhomogeneous order parameter with a phase fluctuation correlation length smaller than the system size. Our results indicate that, by tuning disorder, the Goldstone mode may be observed experimentally in metallic superconductors based for instance on Al, Sn, Pb or Nb.

TT 22.3 Thu 13:30 P

Andreev bound states in disordered superconductors — •Idan Tamir — FU Berlin

At strong enough disorder, superconductivity losses its uniformity and exhibits local gap variations. These are considered a precursor for the eventual breakdown of superconductivity. Using high resolution tunneling spectroscopy to locally study amorphous superconducting films, we observe an abundance of sharp in-gap excitations. We relate these excitations to Andreev bound states induced by either large superconducting gap variations or the interaction with native magnetic impurities. Both possibilities are not accommodated in current theoretical models.

TT 22.4 Thu 13:30 P

Dielectric properties of amorphous indium oxide on the insulating side of the superconductor-insulator transition — Nikolaj Ebensperger[1], Paul Kugler[1], •Anastasia Bauernfeind[1], Martin Dressel[1], Benjamin Sacépé[2], Mikhail Feigel'man[3], and Marc Scheffler[1] — [1]1. Physikalisches Institut, University of Stuttgart, Stuttgart, Germany — [2]Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, Grenoble, France — [3]L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

Amorphous indium oxide (a:InO) plays a prominent role in the study of strongly disordered superconductors. In particular, the disorder-driven transition (SIT) between superconducting and insulating states can be realized. Compared to the superconducting side of the SIT, the insulating side has been explored much less experimentally due to the lack of appropriate experimental means. Here we present dielectric measurements on insulating a:InO, performed at GHz frequencies and at temperatures down to the mK regime, on a set of samples with varying disorder. We obtain the real and imaginary parts of the dielectric function (corresponding to frequency-dependent conductivity) as function of disorder, temperature, and frequency. We analyse these data based on theory for hopping in disordered systems, and we trace the evolution of the dielectric function, e.g. the increase of its real part upon approaching the SIT.

TT 22.5 Thu 13:30 P

Decoupling of superconducting layers in $[(SnSe)_{1+\delta}]_n[NbSe2]_m$ ferecrystals — •O. Chiatti[1], K. Mihov[1], M. Trahms[1], T. Griffin[1], C. Grosse[1], D. Hamann[2], K. Hite[2], M. B. Alemayehu[2], D. C. Johnson[2], and S. F. Fischer[1] — [1]Novel

Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Solid State Chemistry, University of Oregon, Eugene, OR 97403-1253, U.S.A.

Van-der-Waals superlattices with two-dimensional (2D) superconducting layers of a transition-metal dichalchogenide (TMD) embedded between other materials have recently received a lot of attention [1]. Embedding the TMD layers protects them from exposure to air and makes it possible to observe 2D superconductivity. Here, we examine $[(\mathrm{SnSe})_{1+\delta}]_n[\mathrm{NbSe2}]_m$ ferecrystals [2] with $n = 1$ and varying m. The ferecrystals are stacks of polycrystalline layers grown with atomic layer precision, but without an epitaxial relationship between the layers [2]. For $m \leq 9$ we observe a superconducting phase below a critical temperature, which decreases with increasing distance between the $NbSe_2$ monolayers. For $m \geq 9$ an insulating behavior is observed. The Ginzburg-Landau (GL) coherence lengths are determined from the upper critical magnetic fields. The perpendicular GL coherence length decreases with increasing distance between the $NbSe_2$ monolayers, indicating a decoupling of the superconducting layers [3].

[1] A. Devarakonda *et al.*, Science **370**, 231 (2020)
[2] C. Grosse *et al.*, Sci. Rep. **6**, 33457 (2016)
[3] M. Trahms *et al.*, Supercond. Sci. Technol. **31**, 065006 (2018)

TT 22.6 Thu 13:30 P

Resonant microwave spectroscopy close to the superconductor to insulator transition — •Maximilian Kristen[1,2], Jan Nicolas Voss[2], Micha Wildermuth[2], Yannick Schön[2], Andre Schneider[2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2,3,4] — [1]Institut für QuantenMaterialien und Technologien (IQMT), Karlsruher Institut für Technologie — [2]Physikalisches Institut, Karlsruher Institut für Technologie — [3]Russian Quantum Center, Skolkovo, Moscow, Russia — [4]National University of Science and Technology MISIS, Moscow, Russia

High kinetic inductance circuits in the vicinity of the superconductor to insulator transition (SIT) are an interesting research topic not only for applications like quantum circuits or detectors, where the SIT poses a limit on the maximum available kinetic inductance of a wire, but also as a tool to study fundamental aspects of superconductor physics.

We perform microwave measurements on resonators made from highly resistive films. As a material of choice, we use granular aluminum at high oxide levels, due to the low intrinsic loss and the possibility to approach the SIT from the superconducting side. We focus on the low frequency noise behavior of these resonators and present the latest experimental results

TT 22.7 Thu 13:30 P

Growth of superconducting granular aluminum films on cryogenically cooled substrates — •Aniruddha Deshpande, Jan Pusskeiler, Martin Dressel, and Marc Scheffler — 1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

Granular aluminum (grAl) consisting of nanometer-sized aluminum grains separated by aluminum oxide has peculiar superconducting properties. The critical temperature can be substantially enhanced compared to pure bulk aluminum up to 3.7K and the low superfluid density of grAl is promising for applications in quantum circuits. The material properties of grAl can be tuned during thin-film growth by parameters such as oxygen pressure and substrate temperature. Here we use thermal evaporation of aluminum and deposition in low-pressure oxygen environment onto cryogenically cooled substrates to reduce the grain size compared to room-temperature growth, and we characterize the grAl films for their temperature-dependent sheet resistance and their superconducting critical temperature.

TT 22.8 Thu 13:30 P

Modified properties of disordered superconducting films with amorphous and granular structure — •Mariia Sidorova[1,2], Alexej Semenov[1], Stephan Steinhauer[3], Samuel Gyger[3], Val Zwiller[3], Xiaofu Zhang[4], Andreas Schilling[4], and Heinz-Wilhelm Hübers[1,2] — [1]DLR, Institute of Optical Sensor Systems, Berlin, Germany — [2]Humboldt-Universität zu Berlin, Berlin, Germany — [3]KTH Royal Institute of Technology, Stockholm, Swede — [4]University of Zürich, Zürich, Switzerland

Thin disordered superconducting films are intensively exploited in various superconducting devices, for instance, superconducting single-photon detectors (SSPDs) and hot-electron bolometers (HEBs). The dimensionality of such films usually duffers with respect to various physical phenomena, for instance, it is two-dimensional (2d) to superconductivity and weak localization, three-dimensional (3d) to normal conduction, and approach a 2d-3d crossover with respect to phonons. Properties of low-dimensional systems differ from bulk materials and their either theoretical or empirical description remains very limited.

We have studied several superconducting films with thicknesses below 10 nm and different morphology: amorphous WSi and polycrystalline granular NbN and NbTiN. Employing magnetoconductance and calorimetric measurements, we derived an electron-phonon scattering rate and determined sound velocities and phonon heat capacities. Our results indicate a systematic reduction of the sound velocity in all films as compared to the corresponding bulk crystalline material, and a significant impact of the film morphology on the phonon heat capacity.

TT 22.9 Thu 13:30 P

Multifractal correlations of the local density of states in dirty superconducting films — •Matthias Stosiek — Sophia University, Physics Division, Tokyo, Japan

Mesoscopic fluctuations of the local density of states encode multifractal correlations in disordered electron systems. We study fluctuations of the local density of states in a superconducting state of weakly disordered films. We perform numerical computations in the framework of the disordered attractive Hubbard model on two-dimensional square lattices. Interactions are taken into account within mean-field approximation. Our numerical results are explained by an analytical theory. The numerical data and the theory together form a coherent picture of multifractal correlations of the local density of states in weakly disordered superconducting films. [1]

[1] M. Stosiek, F. Evers, I. S. Burmistrov, arXiv:2107.06728 (2021)

TT 23: Poster Session: Emerging Phenomena in Superconducting Low Dimensional Hybrid Systems

Time: Thursday 13:30–15:30 Location: P

TT 23.1 Thu 13:30 P

Electronic structure and charge density wave order in monolayer NbS_2 — •Timo Knispel[1], Jeison A. Fischer[1], Jan Berges[2], Arne Schobert[2], Erik van Loon[2,3], Wouter Jolie[1], Daniela Mohrenstecher[1], Tim Wehling[2], and Thomas Michely[1] — [1]Institute of Physics II, University of Cologne, Zülpicher Str. 77, 50937 Cologne, Germany — [2]Institut für Theoretische Physik, Bremen Center for Computational Materials Science and MAPEX Center for Materials and Processes, Otto-Hahn-Allee 1, University of Bremen, 28359 Bremen, Germany — [3]Department of Physics, Lund University, Professorsgatan 1, 223 63, Lund, Sweden

We investigated monolayer 1H-NbS_2 grown in-situ on graphene/Ir(111) by high-resolution scanning tunneling microscopy and spectroscopy at temperatures down to 0.4K. The characteristic 3x3 CDW pattern is present only in the monolayer, but absent in the bilayer. We analyze the CDW gap, contrast inversion in the dI/dV maps towards both sides of the gap and the suppression of the CDW pattern in the gap. Furthermore, quasiparticle interference is observed at island edges and defects and enables us to measure the dispersion of the hole-like pocket around the Γ-point. Density of states, dispersion around the Γ-point and the properties of the CDW are compared to density functional theory calculations.

Support from the Deutsche Forschungsgemeinschaft, CRC 1238 (project number 277146847, subprojects A01 and B06) is gratefully acknowledged.

TT 23.2 Thu 13:30 P

Dynamics of collective modes in an unconventional charge density wave system $BaNi_2As_2$ — •Amrit raj Pokharel[1], Vladimir Grigorev[1], Arjan Mejas[2], Amir a. Haghighirad[3], Rolf Heid[3], Yi Yao[3], Michael Merz[3], Matthieu Le tacon[3], and Jure Demsar[1] — [1]Institute of Physics, JGU Mainz, Mainz, Ger-

many — [2]Institute of Solid State Physics, TU Wein, Vienna, Austria — [3]Institute of Quantum Materials and Technologies, KIT, Karlsruhe, Germany

$BaNi_2As_2$ is a non-magnetic analogue of $BaFe_2As_2$, the parent compound of a prototype pnictide high temperature superconductor displaying superconductivity already at ambient pressure. Recent diffraction studies demonstrated the existence of two types of periodic lattice distortions above and below the triclinic phase transition, suggesting the existence of an unconventional charge-density-wave (CDW) order. Upon doping, CDW order is suppressed, resulting in a sixfold increase of the superconducting transition temperature and enhanced nematic fluctuations. Here, we apply time-resolved optical spectroscopy to investigate collective response of the CDWs in $BaNi_2As_2$. By performing temperature and excitation density dependent studies we demonstrate the existence of collective modes of the CDW order. The smooth evolution of these modes through the structural phase transition implies the CDW order in the triclinic phase evolves from the unidirectional CDW in the tetragonal phase and may indeed trigger the structural phase transition.

[1] V. Grigorev, et. al., arXiv:2102.09926 (2021)

TT 23.3 Thu 13:30 P

Electronic phase diagram of the excitonic insulator candidates $Ta_2Ni(Se_{1-x}S_x)_5$ — •Pavel Volkov[1], Mai Ye[1], Himanshu Lohani[2], Irena Feldman[2], Amit Kanigel[2], and Girsh Blumberg[1,3] — [1]Rutgers University — [2]Technion — [3]NICPB, Tallin

Excitonic insulator is a phase driven by Coulomb attraction between electrons and holes leading to a proliferation of particle-hole pairs. However, excitonic insulators break lattice symmetries, raising the question of whether a particular transition is excitonic or structural. I will demonstrate that electronic Raman scattering can be used to elucidate the transition origin in the $Ta_2Ni(Se_{1-x}S_x)_5$ family of candidate materials. In particular, at low x the transition is excitonic-driven and shows deviations from mean-field predictions indicating strong correlations. At large sulfur content, the contribution of excitons diminishes and the transition becomes purely structural. The study reveals a quantum phase transition of an excitonic insulator masked by a preemptive structural order.

TT 24: Poster Session: Transport

Time: Thursday 13:30–16:00 Location: P

TT 24.1 Thu 13:30 P

Efficient steady-state solver for the hierarchical equations of motion approach: formulation and application to charge transport through nanosystems — •Christoph Kaspar and Michael Thoss — University of Freiburg

We present an iterative algorithm [1] to efficiently solve the hierarchical equations of motion (HEOM) [2,3] for the steady-state of open quantum systems. The approach reduces the computational resources required by traditional steady-state solvers, in particular for larger systems or the low temperature regime. It uses the method of matrix equations in combination with a efficient preconditioning technique and a hierarchy truncation scheme. We illustrate the numerical performance of the method by applications to models of charge transport in single-molecule junctions.

[1] Kaspar *et al.*, J. Phys. Chem. A **125**, 23, 5190-5200 (2021)
[2] Jin *et al.*, J. Chem. Phys. **128**, 234703 (2008)
[3] Tanimura, J. Chem. Phys. **153**, 020901 (2020)

TT 24.2 Thu 13:30 P

Spin-orbit interaction induces charge beatings in a lightwave-STM – single molecule junction — •Moritz Frankerl and Andrea Donarini — Institute for Theoretical Physics, University of Regensburg, 93049 Regensburg, Germany

Experiments based on lightwave-STM have shown how to obtain both space and time resolution of single molecule vibrations on their intrinsic length and time scales [1]. We investigate theoretically the electronic dynamics of a copper-phthalocynanine in a lightwave-STM by simulating the full pump-probe cycle [2]. Beatings in the transferred charge reveal the intertwined spin and orbital dynamics, modulated by a tip induced exchange field [3]. We study the dynamics directly in the time domain within a generalized master equation approach. A deeper understanding of our numerical results is obtained via coupled Bloch like equations for the molecular spin and pseudospin [4].

[1] T. L. Cocker et al., Nature 539, 263-267 (2016)
[2] M. Frankerl et al, Phys. Rev. B 103, 085420 (2021)
[3] M. Braun et al., Phys. Rev. B 70, 195345 (2004)
[4] M. Maurer et al., Phys. Rev. Research 2, 033440 (2020)

TT 24.3 Thu 13:30 P

Pseudospin resonances reveal synthetic spin-orbit interaction — •Christoph Rohrmeier and Andrea Donarini — Institute of Theoretical Physics University of Regensburg, Regensburg, Germany

The interplay between interference and interaction produces several effects in degenerate quantum systems, including spin torques [1], dark states formation [2] and multilevel coherences [3]. In this context, a spin resonance without spin splitting has been first predicted for a single quantum dot spin valve [4]. We investigate a spinful double quantum dot coupled to leads in a pseudospin valve configuration. We predict in the stability diagram a rich variety of current resonances which are modulated by the system parameters [5]. In the presence of ferromagnetic leads and pseudospin anisotropy, those resonances split, turn into dips, and acquire a Fano shape, thus revealing a synthetic spin-orbit interaction induced on the double quantum dot. A set of rate equations derived for a minimal model captures those features. The model accurately matches the numerical results obtained for the full system in the framework of a generalized master equation and calculated within the next to leading order approximation.

[1] M. Braun et al., Phys. Rev. B 70, 195345 (2004)
[2] A. Donarini et al., Nature Comm. 10, 381 (2019)
[3] M. Maurer et al., Phys. Rev. Research 2, 033440 (2020)
[4] M. Hell et al., Phys. Rev. B 91, 195404 (2015)
[5] C. Rohrmeier et al., Phys. Rev. B 103, 205420 (2021)

TT 24.4 Thu 13:30 P

Feynman-Vernon influence functional approach to quantum transport in interacting nanojunctions: An analytical hierarchical study — •Luca Magazzu and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany

We present a nonperturbative and formally exact approach for the charge transport in interacting nanojunctions based on the Feynman-Vernon influence functional. By borrowing the nomenclature of the famous spin-boson model, we parametrize the two-state dynamics of each single-particle fermionic degree of freedom, in the occupation number representation, in terms of blips and sojourns. We apply our formalism to the exactly solvable resonant level model (RLM) and to the single-impurity Anderson model (SIAM), the latter being a prototype system for studying strong correlations. For both systems, we demonstrate a hierarchical diagrammatic structure. While the hierarchy closes at the second-tier for the RLM, this is not the case for the interacting SIAM. Upon inspection of the current kernel, known results from various perturbative and nonperturbative approximation schemes to quantum transport in the SIAM are recovered. Finally, a novel noncrossing approximation for the hierarchical kernel is developed, which enables us to systematically decrease temperature at each next level of the approximation.

[1] arXiv:2104.14497 (2021)

TT 24.5 Thu 13:30 P

An Atomistic Study of the Thermoelectric Signatures of CNT Peapods — •Alvaro Gaspar Rodriguez Mendez[1,2], Leonardo Medrano Sandonas[3], Arezoo Dianat[1], Rafael Gutierrez[1], and Gianaurelio Cuniberti[1] — [1]Institute for Materials Science and Max Bergmann Center of Biomaterials, Tu Dresden, 01062 Dresden, Germany. — [2]Max Planck Institute for Complex Systems, 01187 Dresden, Germany. — [3]Physics and Materials Science Research Unit, University of Luxembourg, L-1511 Luxembourg.

Carbon-based nanomaterials have a great potential for the development of high performance thermoelectric (TE) materials because of their low-cost and for being environmentally friendly. Carbon nanotubes have, however, high electrical and thermal conductivities so that further nanoscale engineering is required to exploit them as TE materials. We investigate electron and phonon transport in CNT peapods to elucidate their potential advantage over pristine CNTs. We show their transport properties are sensitively modified by C60 encapsulation, when the CNT-C60 intermolecular interaction is strong enough to produce a periodic buckling of the CNT walls. Moreover, the phonon transmission is strongly suppressed at low and high frequencies, leading to a reduction of the phonon contribution to the overall thermal conductance, similar effect observed in recently proposed phononic metamaterials. We obtain in general a larger TE figure of merit over a broad temperature range for the CNT peapod when compared with the pristine CNT. Our findings show an alternative route for the enhancement of the TE performance of CNT-based devices.

TT 24.6 Thu 13:30 P

Evolution of Molecular Binding in Mechanically Controlled Break-Junctions — •Lokamani Lokamani[1,3], Florian Günther[2], Filip Kilibarda[3], Jeffrey Kelling[1], Guido Juckeland[1], Artur Erbe[3], and Sibylle Gemming[4] — [1]Department of Information Services and Computing, HZDR, Dresden, Germany — [2]Instituto de Física de São Carlos, Universidade de São Paulo, Brazil — [3]Department of Ion Beam Physics and Materials Research, HZDR, Dresden, Germany — [4]Institute of Physics, Technische Universität Chemnitz, Chemnitz, Germany

Electrical properties of single molecules can be investigated with extreme precision using atomically sharp metallic electrodes in mechanically controllable break junctions (MCBJs). The current-voltage (IV) characteristics in such junctions are considerably affected by the binding positions of the anchoring groups on the tip-facets and the configuration of the molecule. Hence, characterizing the electronic transport properties during a single tip-tip opening provides interesting insights into the tip-molecule interaction.

Here, we present a novel high-throughput approach to reproduce the time evolution of the electronic transport characteristics. We performed transport calculations using the self-consistent charge scheme of the density-functional-based tight binding approach and the Green's function formalism. In particular, we evaluated the energy level and the coupling of the dominating transport channel using the single level model. In contrast to standard approaches, we consider many thermodynamically relevant configurations.

TT 24.7 Thu 13:30 P

Revealing channel polarization of atomic contacts of ferromagnets and strong paramagnets by shot-noise measurements — Martin Prestel, •Marcel Strohmeier, Wolfgang Belzig, and Elke Scheer — University of Konstanz, 78457 Konstanz, Germany

We report measurements of the shot noise of atomic contacts using the mechanically controllable break junction (MCBJ) technique at low temperatures. In accordance with theoretical predictions [1, 2] single-atom contacts of the ferromagnets Co and Gd with conductance smaller than the conductance quantum show reduced noise compared to the expectation for the spin-degenerate single-channel transport. Additionally we focus on the strong paramagnets Pt [3], Pd [4], and Ir [5], where a nonmonotonic magnetotransport has been reported for atomic contacts, interpreted as emerging magnetic ordering in small dimension, which is expected due to the Stoner instability [6, 7]. Our recent measurements on Pd, Pt, and Ir reveal noise levels which are above, but close to the threshold to the spin-degenerate single-channel situation. An anticorrelation between the minimum noise and the bulk Stoner parameter of these elements is observed. We discuss by how far this might indicate that spin polarization is reflected in the noise signal.

[1] Olivera et al., PRB 95, 075409 (2017)
[2] Häfner et al., PRB 77, 104409 (2008)
[3] Strigl et al., Nature Comm. 6, 6172 (2015)
[4] Strigl et al., PRB 94, 144431 (2016)
[5] Prestel et al., PRB 100, 214439 (2019)
[6] Delin et al., PRL 92, 057201 (2004)
[7] Delin et al., PRB 68, 144434 (2003)

TT 24.8 Thu 13:30 P

Theory of coherent phonon mode excitation in metal nanoparticles — •Robert Salzwedel[1], Dominik Hoeing[2], Yannic Staechelin[2], Florian Schulz[2], Holger Lange[2], Andreas Knorr[1], and Malte Selig[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institut für Physikalische Chemie, Universität Hamburg, 20146 Hamburg, Germany

Metal nanoparticles perform radial breathing mode oscillation upon excitation by a light pulse. Typically, these oscillations are assumed to be driven by the thermalization of hot electrons that impulsively heat the lattice [1,2].

Here we present a hydrodynamic theory based on the Heisenberg equation of motion formalism for the optical excitation of the electron gas in metal nanoparticles and the related electron-phonon interaction.

Our analysis reveals that spatial gradients of the electron density which are induced by the optical pump already drive coherent phonon oscillations whereas thermalization is found to be of reduced importance.

[1] Hodak, J. H. et al. (1999), *JOCP*, **111**(18)
[2] Ng, M. Y. et al. (2011), *JOCP*, **134**(9), 094116

TT 24.9 Thu 13:30 P

Direct current from AC driving of Dirac Fermions — •Adrian Seith, Jakob Schlosser, Jan Wilhelm, and Ferdinand Evers — Institut für Theoretische Physik, Universy of Regensburg, Germany

Recent developments in systems driven by an ultra-short laser pulse demonstrate the high-order harmonic generation in topological systems with a Dirac-type (surface) bandstructure [1]. We investigate the current-density that results from the laser pulse close to the surface. Simulations based on the Semiconductor Bloch equations as implemented in the CUED code [2] indicate the emergence of a DC-like current with a lifetime by far exceeding the pulse duration. An analytical solution within a model system of Dirac Fermions is possible explaining the effect rigorously together with the observed dependence on the carrier envelope phase (CEP). Consequences for experiments with realistic band structures are discussed, as well as applications to light-wave-electronics.

[1] Schmid et. al., Nature 593, 385 (2021)
[2] Wilhelm et. al., Phys. Rev. B 103, 125419 (2021)

TT 24.10 Thu 13:30 P

Laser-waveform control of high-harmonic emission - a theoretical analysis — •Jan Wilhelm, Maximilian Graml, Maximilian Nitsch, Patrick Grössing, and Ferdinand Evers — Institute of Theoretical Physics, University of Regensburg

When irradiating solids with a short, i.e. subcycle, laser pulse, the corresponding electric field initiates ultrafast electron dynamics in the material. Fingerprints of it are encoded in the emission spectrum that features high-harmonic generation. High-harmonic emission from a topological insulator has been observed recently in experiment [1] opening a platform to explore topology and quasi-relativistic quantum physics using strong laser fields. Strikingly, the high-harmonic orders can be shifted to non-integer multiples of the driving frequency by varying the carrier-envelope phase (CEP) of the driving field. We theoretically analyze the mechanisms leading to CEP shifts using semiconductor Bloch equations [2-4] finding that an interplay of chirp and CEP of the laser pulse lead to arbitrary CEP shifts.

[1] C. P. Schmid, et al., Nature 593, 385-390 (2021)
[2] W. Schäfer, M. Wegener, Semiconductor Optics and Transport Phenomena, Springer, Berlin (2002)
[3] M. Kira, S. W. Koch, Semiconductor Quantum Optics, Cambridge University Press (2011)
[4] J. Wilhelm, P. Grössing, A. Seith, J. Crewse, M. Nitsch, L. Weigl, C. Schmid, F. Evers, Phys. Rev. B 103, 125419 (2021)

TT 24.11 Thu 13:30 P

High-harmonic geneneration in topological insulator surface states — •Vanessa Junk[1], Cosimo Gorini[1,2], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg, Germany — [2]Université Paris-Saclay, CEA, CNRS, SPEC, 91191, Gif-sur-Yvette, France

High-order harmonics are typically generated when matter is interacting with strong-field light. In most materials efficient scattering and dephasing destroy coherences in the emitted spectra. In topological insulator (TI) surface states however, scattering is strongly suppressed. This opens up the possibility to observe signatures of coherent transport.

We present how Berry curvature effects imprint into the dynamics of strong-field light driven electrons in TI surface states. In the semiclassical framework, a non-zero Berry curvature leads to the emergence of a velocity component perpendicular to the external driving. Here, we compare the semiclassical predictions with a full quantum mechanical simulation. The high harmonics spectra we calculate from the dynamics show an alternating polarization as has recently also been observed in experiment [1].

[1] C. Schmid, L. Weigl, P. Grössing, V. Junk, C. Gorini, S. Schlauderer, S. Ito, M. Meierhofer, N. Hofmann, D. Afanasiev, J. Crewse, K. Kokh, O. Tereshchenko, J. Güdde, F. Evers, J. Wilhelm, K. Richter, U. Höfer and R. Huber, Nature **593**, 385-390 (2021)

TT 25: Poster Session: Topology

Time: Thursday 13:30–16:00 Location: P

TT 25.1 Thu 13:30 P

Boosting the surface conduction in a topological insulator — •Mathieu Taupin[1], Gaku Eguchi[1], Monika Budnovski[1], Andreas Steiger-Thirsfeld[2], Yukiaki Ichida[3], Kenta Kuroda[3,4], Shik Shin[3], Akio Kimura[4], and Silke Paschen[1] — [1]Institute of Solid State Physics, TU Wien, Austria — [2]USTEM, TU Wien, Austria — [3]ISSP, The University of Tokyo, Japan — [4]Graduate School of Advanced Science and Engineering, Hiroshima University, Japan

Despite the intense research on topological insulators, manipulating the surface states by the application of external stimuli is surprisingly only little explored. For instance, some topological insulators have been shown to have an anomalous response when exposed to light, i.e. slow with non-exponential behaviour. These results hint on the tunability of the Dirac states with illumination, but the lack of consensus of the microscopic mechanism impedes progress.

Our work provides an understanding of these effects. We demonstrate that under external excitation (such as thermal radiation, light illumination and current driving), excited electrons will migrate to the surface states and remain there “permanently” due to the intrinsic Schottky barrier and space-charge separation between the surface and bulk carriers. This leads to a significant boost of the surface conduction, even in a bulk sample, which can be adjusted with the amplitude of the external excitation. We find striking similarities between our results and previous spectroscopic studies and propose a common mechanism, which is in principle applicable in any topological insulators.

TT 25.2 Thu 13:30 P

Dirac-like particles in a box in shaped topological insulator nanowires — •Maximilian Fürst, Michael Barth, Cosimo Gorini, and Klaus Richter — Universität Regensburg

Topological insulator nanowires exhibit strong spin-orbit coupling with surface states which are well-protected against backscattering [1]. Due to their Dirac-like dispersion they are intersting materials for studying emergent relativistic effects in condensed matter. We show how TI nanowires can be used to generate Dirac-like particles in a box by exploiting geometrical properties of the wires and applying an external coaxial magnetic field. These quantized energy levels can be probed by conductance calculations. In order to do that, we employ the numerical Python package kwant [2] and implement a shaped 3D topological insulator nanowire with a 3D bulk model as well as an effective 2D surface model. Quantized and flux dependent conductance lines exhibit strong constraints on the physical state of the trapped electrons what makes a practical application as a magnetically tunable momentum filter possible.

[1] X.-L. Qi and S.-C. Zhang, Rev. Mod. Phys. 83, 1057 (2011)
[2] Ch. W. Groth et al., New J. Phys. 16, 063065 (2014)

TT 25.3 Thu 13:30 P

Anisotropic Nodal-Line-Derived Large Anomalous Hall Conductivity in ZrMnP and HfMnP — •Sukriti Singh, Jonathan Noky, Shaileyee Bhattacharya, Praveen Vir, Yan Sun, Nitesh Kumar, Claudia Felser, and Chandra Shekhar — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

The nontrivial band structure of semimetals has attracted substantial research attention in condensed matter physics and materials science in recent years owing to its intriguing physical properties. Within this class, a group of non-trivial materials known as nodal-line semimetals is particularly important. Nodal-line semimetals exhibit the potential effects of electronic correlation in nonmagnetic materials, whereas they enhance the contribution of the Berry curvature in magnetic materials, resulting in high anomalous Hall conductivity (AHC). In this study, two ferromagnetic compounds, namely ZrMnP and HfMnP, are selected, wherein the abundance of mirror planes in the crystal structure ensures gapped nodal lines at the Fermi energy. These nodal lines result in one of the largest AHC values of 2840 ohm-1cm-1, with a high anomalous Hall angle of 13.6% in these compounds. First-principles calculations provide a clear and detailed understanding of nodal line-enhanced AHC. Our finding suggests a guideline for searching large AHC compounds.

TT 25.4 Thu 13:30 P

Observation of symmetry-enforced topological nodal planes in CoSi — Nico Huber[1], •Kirill Alpin[2], Grace L. Causer[1], Lukas Worch[1], Andreas Bauer[1], Georg Benka[1], Moritz M. Hirschmann[2], Andreas P. Schnyder[2], Christian Pfleiderer[1,3,4], and Marc A. Wilde[1] — [1]Physik Department, Technische Universität München, Garching, Germany — [2]Max-Planck-Institute for Solid State Research, Stuttgart, Germany — [3]MCQST, Technische Universität München, Garching, Germany — [4]Centre for Quantum Engineering (ZQE), Technische Universität München, Garching, Germany

In this work, we present a complete topological classification of CoSi, whose bandstructure features a plethora of Weyl points, topologically charged multifold crossings, and symmetry-enforced nodal planes. The latter are forced to have nonzero charges in the presence of SOC, which we show both theoretically for a general case and computationally via DFT calculations for CoSi, using an adaptive mesh of Wilson loops. The total charge is found to be consistent with the fermion doubling theorem. Resulting topological protectorates, intersections of the Fermi surface with topological nodal planes, are detected via measurements of Shubnikov-de Haas oscillations.

TT 25.5 Thu 13:30 P

Kerr effect in tilted nodal loop semimetals — Johan Ekström[1], Eddwi H. Hasdeo[1,2], Maria Belén Farias[1], and •Thomas L. Schmidt[1] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg — [2]Research Center for Physics, Indonesian Institute of Sciences, South Tangerang, Indonesia

We investigate the optical activity of tilted nodal loop semimetals. We calculate the full conductivity matrix for a band structure containing a nodal loop with possible tilt in the $x-y$ plane, which allows us to study the Kerr rotation and ellipticity both for a thin film and a bulk material. We find signatures in the Kerr signal that give direct information about the tilt velocity and direction, the radius of the nodal loop and the internal chemical potential of the system. These findings should serve as a guide to understanding optical measurements of nodal loop semimetals and as an additional tool to characterize them.

TT 25.6 Thu 13:30 P

Impurity-induced bound states and resonances in lattice Dirac-Weyl semimetals — •João P. Santos Pires[1], Bruno Amorim[2], and João M. Viana Parente Lopes[1] — [1]Centro de Física das Universidades do Minho e Porto, University of Porto, 4169-007 Porto, Portugal — [2]Centro de Física das Universidades do Minho e Porto, University of Minho, 4710-057 Braga, Portugal

The discovery of gapless 3D semimetals turned Dirac-Weyl electrons into a hot topic in condensed matter. The possibility of a putative impurity- or disorder-driven quantum phase transition that turns a semi-metallic phase (with vanishing DoS at the Fermi level) into a diffusive metallic phase have attracted particular interest. Despite the vast number of recent work addressing this problem, the picture remains unclear and seemingly dependent on the precise type of disorder considered.

In this work, we use a projected Green function method to study a four-band gapless Dirac Hamiltonian discretised in a simple cubic lattice, and in the presence of impurities composed of spherical clusters with on-site energy U. With this method, we evaluate the correction to the total and local density of states induced by the impurity. For cluster of radius larger than one lattice spacing, we found that eigenstates bound to the impurity cluster are formed, at fine-tuned values of U that depart from the predictions from the continuum theory. As this radius is increased, the lattice results progress towards the continuum theory predictions.

TT 25.7 Thu 13:30 P

Artificial event horizons in Weyl semimetal heterostructures and their non-equilibrium signatures — •Christophe De Beule[1], Solofo Groenendijk[1], Tobias Meng[2], and Thomas L. Schmidt[1] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg — [2]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01069 Dresden, Germany

We investigate transport in type-I/type-II Weyl semimetal heterostructures that realize effective black- or white-hole event horizons. We provide an exact solution to the scattering problem at normal incidence and low energies, both for a sharp and a slowly-varying Weyl cone tilt profile. In the latter case, we find two channels with transmission amplitudes analogue to those of Hawking radiation. Whereas the Hawking-like signatures of these two channels cancel in equilibrium, we demonstrate that one can favor the contribution of either channel using a non-equilibrium state, either by irradiating the type-II region or by coupling it to a magnetic lead. This in turn gives rise to a peak in the two-terminal differential conductance which can serve as an experimental indicator of the artificial event horizon.

TT 25.8 Thu 13:30 P

Crossed Andreev reflection in topological insulator nanowire T-junctions — •Jacob Fuchs[1], Michael Barth[1], Cosimo Gorini[1,2], Inanc Adagideli[3,4], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Université Paris-Saclay, CEA, CNRS, SPEC, 91191, Gif-sur-Yvette, France — [3]Faculty of Engineering and Natural Sciences, Sabanci University, 34956 Orhanli-Tuzla, Turkey — [4]Faculty of Science and Technology and MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands

We numerically study crossed Andreev reflection (CAR) in a topological insulator nanowire T-junction where one lead is proximitized by a superconductor. We find that CAR should be clearly observable in a wide parameter range, including perfect CAR in a somewhat more restricted range. Furthermore, it can be controlled by a magnetic field and is robust to disorder.

TT 25.9 Thu 13:30 P

Improving topological superconductivity in two- and three-dimensional Josephson junctions — •Aidan Wastiaux[1] and Falko Pientka[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]Institute of Theoretical Physics, Goethe University, Frankfurt am Main

As opposed to the numerous theoretical developments in the field of topological heterostructures hosting robust quasiparticles, difficulties are piling up for experimentalists on their way to building realistic and tunable setups with usable topological states. We address this widespread issue in a specific platform involving a planar Josephson junction made of a semiconductor with strong spin-orbit coupling by proposing easy-to-reach regimes of parameters with enhanced stability of the Majorana end states. Moreover, the extension of those findings to a three-dimensional model provides henceforth a new flexible platform for realizing chiral Majorana edge states. Possible setups using Van der Waals heterostructures are suggested.

TT 25.10 Thu 13:30 P

Weyl systems: anomalous transport normally explained — •Klaus Morawetz — Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil

The anomalous term $\sim \vec{E}\vec{B}$ in the balance of the chiral density can be rewritten as quantum current in the classical balance of density. This term is derived from the quantum kinetic equations for systems with SU(2) structure within a completely conserving approach and it is suggested that the term is of kinetic origin instead of anomaly. Regularization-free density and pseudospin currents are calculated in Graphene and Weyl-systems realized as the infinite-mass limit of electrons with quadratic dispersion and a proper spin-orbit coupling. The intraband and interband conductivities are discussed. The optical conductivity agrees well with the experimental values using screened impurity scattering and an effective Zeeman field. The universal value of Hall conductivity is shown to be modified due to the Zeeman field.

[1] Eur. Phys. J. B 92 (2019) 176
Phys. Lett. A 383 (2019) 1362
[2] Phys. Rev. B 94 (2016) 165415
[3] Phys. Rev. B 92 (2015) 245425
[4] errata: Phys. Rev. B93 (2016) 239904(E)
[5] Phys. Rev. B 92 (2015) 245426

TT 25.11 Thu 13:30 P

Current correlations of Cooper-pair tunneling into a quantum Hall system — Andreas Michelsen[1,2], Thomas Schmidt[1], and •Edvin Idrisov[1] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg — [2]SUPA, School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews KY16 9SS, United Kingdom

We study Cooper-pair transport through a quantum point contact between a superconductor and a quantum Hall edge state at integer and fractional filling factors. We calculate the tunneling current and its finite-frequency noise to the leading order in the tunneling amplitude for dc and ac bias voltage in the limit of low temperatures. At zero temperature and in the case of tunneling into a single edge channel both the conductance and differential shot noise vanish as a result of the Pauli exclusion principle. In contrast, in the presence of two edge channels, this Pauli blockade is softened and a nonzero conductance and shot noise are revealed.

TT 25.12 Thu 13:30 P

Universal Hall conductance scaling in non-Hermitian Chern insulators — •Solofo Groenendijk[1], Thomas Schmidt[1], and Tobias Meng[2] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg — [2]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01069 Dresden, Germany

We investigate the Hall conductance of a two-dimensional Chern insulator coupled to an environment causing gain and loss. Introducing a biorthogonal linear response theory, we show that sufficiently strong gain and loss lead to a characteristic nonanalytical contribution to the Hall conductance. Near its onset, this contribution exhibits a universal power law with a power 3/2 as a function of Dirac mass, chemical potential, and gain strength. Our results pave the way for the study of non-Hermitian topology in fermionic transport experiments.

TT 25.13 Thu 13:30 P

Origin of the quasi-quantized Hall effect in $ZrTe_5$ — •Stanislaw Galeski and Johannes Gooth — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

The quantum Hall effect (QHE) is traditionally considered to be a purely two-dimensional (2D) phenomenon. Recently, however, a three-dimensional (3D) version of the QHE was reported in the Dirac semimetal $ZrTe_5$. It was proposed to arise from a magnetic-field-driven Fermi surface instability, transforming the original 3D electron system into a stack of 2D sheets. Here, we report thermodynamic, spectroscopic, thermoelectric and charge transport measurements on such $ZrTe_5$ samples. The measured properties: magnetization, ultrasound propagation, scanning tunneling spectroscopy, and Raman spectroscopy, show no signatures of a Fermi surface instability, consistent with in-field single crystal X-ray diffraction. Instead, a direct comparison of the experimental data with linear response calculations based on an effective 3D Dirac Hamiltonian suggests that the quasi-quantization of the observed Hall response emerges from the interplay of the intrinsic properties of the $ZrTe_5$ electronic structure and its Dirac-type semi-metallic character.

TT 25.14 Thu 13:30 P

Generalized Chern numbers based on open system Green's functions — Maria Belén Farias, •Solofo Groenendijk, and Thomas Schmidt — Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg

We present an alternative approach to studying topology in open quantum systems, relying directly on Green's functions and avoiding the need to construct an effective non-Hermitian (nH) Hamiltonian. We define an energy-dependent Chern number based on the eigenstates of the inverse Green's function matrix of the system which contains, within the self-energy, all the information about the influence of the environment, interactions, gain or losses. We explicitly calculate this topological invariant for a system consisting of a single 2D Dirac cone and find that it is half-integer quantized when certain assumptions about the self-energy are made. Away from these conditions, which cannot or are not usually considered within the formalism of nH Hamiltonians, we find that such a quantization is usually lost and the Chern number vanishes, and that in special cases, it can change to integer quantization.

TT 25.15 Thu 13:30 P

Geometrical Rabi oscillations in non-Abelian systems — •Hannes Weisbrich[1], Gianluca Rastelli[2], and Wolfgang Belzig[1] — [1]Universität Konstanz — [2]Universita di Trento

Topological phases of matter became a new standard to classify quantum systems in many cases, yet key quantities like the quantum geometric tensor providing local information about topological properties are still experimentally hard to access, especially in non-Abelian systems [1] when states are degenerate and the quantum geometric tensor has a non-Abelian form. We propose protocols to determine the quantum geometric tensor in non-Abelian quantum systems. We show theoretically that for a weak resonant driving of the local parameters the coherent Rabi oscillations and their frequencies are related to the non-Abelian quantum geometric tensor [2]. Our schemes suggest also a way to prepare eigenstates of the quantum metric, a task that is difficult otherwise in a degenerate subspace.

[1] H. Weisbrich, R. L. Klees, G. Rastellli, and W. Belzig, PRX Quantum 2, 010310 (2021)
[2] H. Weisbrich, G. Rastellli, and W. Belzig, arXiv:2105.02689 (2021); accepted in Phys. Rev. Research (2021)

TT 25.16 Thu 13:30 P

Non-Hermitian band topology from momentum-dependent relaxation in two dimensional metals with spiral magnetism — •Johannes Mitscherling and Walter Metzner — Max Planck Institute for Solid State Research, Stuttgart, Germany

We present the emergence of non-Hermitian band topology in a two dimensional metal with planar spiral magnetism due to a momentum-dependent relaxation rate. A sufficiently strong momentum dependence of the relaxation rate leads to exceptional points in the Brillouin zone, where the Hamiltonian is non-diagonalizable. The exceptional points appear in pairs with opposite topological charges and are connected by arc-shaped branch cuts. We show that exceptional points inside hole and electron pockets, which are generally present in a spiral magnetic state with a small magnetic gap, can cause a drastic change of the Fermi surface topology by merging those pockets at isolated points in the Brillouin zone. The spectral function observed in photoemission exhibits Fermi arcs. Its momentum dependence is smooth - despite of the non-analyticities in the complex quasiparticle band structure.

TT 25.17 Thu 13:30 P

On the origin of the corner modes of the breathing kagome lattice — •Miguel Angel Jimenez Herrera[1,2], María Blanco de Paz[2], Aitzol García Etxarri[2,3], and Dario Bercioux[2,3] — [1]Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU, 20018 Donostia-San Sebastián, Basque Country, Spain — [2]Donostia International Physics Center, 20018 Donostia-San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, Euskadi Plaza, 5, 48009 Bilbao, Spain

Quantum simulating techniques conform a perfect laboratory to study low-dimensional systems, such as the Su-Schrieffer-Heeger model, in 1D, or the breathing kagome model, in 2D [1]. Here, we address the realization of latter model using the muffin tin method, a first-principles-like technique based on planar wave expansion of the Bloch wave function. We study the standard kagome model and the two breathing phases using topological and symmetry markers. We claim that such breathing phases are both atomic limits: one shows zero bulk polarization, while the other, also called obstructed atomic limit, displays a finite value. We have performed a topological quantum chemistry [2] analysis and we have obtained the same result, supporting our results.

[1] Kempkes *et al.*, Nat. Mater. **18**, 1292 (2019)
[2] Bradlyn *et al.*, Nature **547**, 298 (2017)

TT 25.18 Thu 13:30 P

Carrier transitions in gapped Dirac systems induced by strong light pulses — •Mario Ebner[1], Vanessa Junk[1], Cosimo Gorini[1,2], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg, Germany — [2]Université Paris-Saclay, CEA, CNRS, SPEC, 91191, Gif-sur-Yvette, France

In order to understand the interesting consequences of matter interacting with strong light pulses, such as higher harmonics generation, it is necessary to investigate how the light field influences the occupation of the energy bands in the system.

We theoretically study this redistribution of carriers in a Dirac system, such as graphene, in the presence of a mass gap. This is done in two ways: Firstly, we model the behaviour of electrons in the system by a wave packet propagating under the influence of the electric field pulse. Secondly, we want to emphasize another approach similar to [1], which essentially breaks down to solving the time-dependent Schrödinger equation for a single $\boldsymbol{k}$-mode. This gives a complementary view of the physical processes involved. In particular, we discuss the interplay between the motion in reciprocal space due to the electric field and the dipole matrix element between valence and conduction band which determines the observed populations.

As an outlook, we sketch how to deduce the resulting current which can be split in intra- and interband contributions and which can be used for computing higher harmonics spectra.

[1] S. A. O. Motlagh *et al*, J. Phys.: Condens. Matter **32**, 065305 (2020)

TT 26: Annual General Meeting of the Low Temperature Physics Division

Time: Thursday 18:00–19:30 Location: MVTT

Bericht, Wahl, Verschiedenes

TT 27: Topological Insulators and Semimetals (joint session TT/KFM)

Time: Friday 10:00–12:45 Location: H7

TT 27.1 Fri 10:00 H7

Wave-particle duality of electrons with spin-momentum locking — •Dario Bercioux[1,2], Tineke van den Berg[1], Dario Ferrero[3,4,5], Jerome Rech[4], Thibaut Jonckheere[4], and Thierry Martin[4] — [1]Donostia International Physics Center (DIPC), Manuel de Lardizbal 4, E-20018 San Sebastián, Spain — [2]IKERBASQUE, Basque Foundation of Science, 48011 Bilbao, Basque Country, Spain — [3]Aix Marseille Univ, Université de Toulon, CNRS, CPT, Marseille, France — [4]Dipartimento di Fisica, Università di Genova, Via Dodecaneso 33, 16146, Genova, Italy — [5]SPIN-CNR, Via Dodecaneso 33, 16146 Genova, Italy

We investigate the effects of spin-momentum locking on the interference and diffraction pattern of electrons in a double- or single-slit Gedankenexperiment. We show that the inclusion of the spin degree-of-freedom when coupled to the carrier's motion direction — a typical situation occurring in systems with spin-orbit interaction — leads to modify the interference and diffraction patterns depending on the geometrical parameters system.

[1] Bercioux *et al.*, Eur. Phys. J. Plus **135**, 811 (2020)

TT 27.2 Fri 10:15 H7

Volkov-Pankratov states in topological graphene nanoribbons — Tineke L. van den Berg[1], •Alessandro De Martino[2], M. Reyes Calvo[3], and Dario Bercioux[1,4] — [1]Donostia International Physics Center, Donostia-San Sebastián, Spain — [2]Department of Mathematics, City, University of London, London, United Kingdom

— [3]Departamento de Fisica Aplicada, Universidad de Alicante, Alicante, Spain — [4]IKERBASQUE, Basque Foundation of Science, Bilbao, Spain

In topological systems a smooth modulation of the gap at the interfaces between topologically distinct phases can lead to the appearance of massive edge states, as first described by Volkov and Pankratov in 1985. In this contribution I will show that, in the presence of intrinsic spin-orbit coupling smoothly modulated near the edges, graphene nanoribbons host Volkov-Pankratov states in addition to the topologically protected helical states. This result is obtained by means of two complementary methods, one based on the effective low-energy Dirac equation description and the other on a fully numerical tight-binding approach, with excellent agreement between the two. I will then briefly discuss how transport measurements might reveal the presence of Volkov-Pankratov states, and possible graphene-like structures in which such states might be observed.

TT 27.3 Fri 10:30 H7

Symmetry-enforced topological nodal planes — 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]Centre 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.

Topological semimetals and metals may contain nodal points or lines, i.e., zero- or one-dimensional crossings in the energy bands. In the present work we discuss an extension to two-dimensional nodal features. These nodal planes are enforced in crystals with certain nonsymmorphic space groups. We specify the necessary conditions for the existence of nodal planes and consider in the process paramagnetic as well as magnetic space groups. Based on an analysis of symmetry eigenvalues we identify space groups that lead to nodal planes with a non-zero Chern number. Our arguments are supported by minimal models and explicit calculation of the topological invariants. Furthermore, we have identified a number of materials with topological nodal planes. Among them is the ferromagnetic phase of MnSi, for which we show that the symmetry-enforced topological nodal planes exist, using de Haas-van Alphen spectroscopy and density functional theory calculations.

[1] M.A. Wilde et al., Nature 594, 374-379 (2021)

TT 27.4 Fri 10:45 H7

Network of topological nodal planes and point degeneracies in CoSi — •Nico Huber[1], Kirill Alpin[2], Grace L. Causer[1], Lukas Worch[1], Andreas Bauer[1], Georg Benka[1], Moritz M. Hirschmann[2], Andreas P. Schnyder[2], Christian Pfleiderer[1], and Marc A. Wilde[1] — [1]Physik Department, Technische Universität München, D-85748 Garching, Germany — [2]Max-Planck-Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany

We report the experimental identification of symmetry-enforced topological nodal planes in CoSi which together with multifold point degeneracies and Weyl points form a network of band crossings satisfying the fermion doubling theorem. For this, we have combined measurements of Shubnikov-de Haas oscillations in CoSi with material-specific electronic structure calculations and a symmetry analysis [1]. The observation of two nearly dispersionless Shubnikov-de Haas frequency branches is shown to provide clear evidence of four distinct Fermi surface sheets at the R point of the Brillouin zone and of the symmetry-enforced orthogonality of the wave functions at the intersections with the nodal planes. These results highlight that CoSi features six- and fourfold crossings at R and Γ and that a comprehensive account of all topological charges in the network going beyond point degeneracies is needed.

[1] Huber et al., arXiv:2107.02820

15 min. break.

TT 27.5 Fri 11:15 H7

Twisted and chiral photon states scattered on chiral molecular liquids — Silvia Müllner[1], Florian Büscher[1], Dirk Wulferding[2], Yurii G. Pashkevich[1,3], Vladimir Gnezdilov[1,4], Anton A. Pechkov[5], Andrey Surzhykov[5], and •Peter Lemmens[1] — [1]IPKM, TU Braunschweig, Germany — [2]CCES, Inst. for Basic Science, Seoul, Republic of Korea — [3]O.O. Galkin Donetsk Inst. for PaE, NASU, Kyiv - Kharkiv, Ukraine — [4]B. Verkin Inst. for Low Temp. Phys and Eng., NASU, Kharkiv, Ukraine — [5]Inst. Math. Phys., TU Braunschweig and PTB, Braunschweig, Germany

Twisted or structured light [1] has been recognized as a novel probe of chiral states of matter. The respective light matter coupling is still discussed controversially. Using resonant light-matter coupling of twisted and chiral photon states [1] to chiral molecular liquids we study their inelastic response. For this instance, quasi-elastic Raman scattering (QES) is investigated in isotropic, nematic and chiral nematic phases of liquid crystals. The response is diffusive and dominated by a narrow distribution or single relaxation rate.

We acknowledge important discussions with G. Napoli (Univ. del Salento, Lecce). This research was funded by the DFG Excellence Cluster QuantumFrontiers, EXC 2123, DFG Le967/16-1, DFG-RTG 1952/1, and the Quantum- and Nano-Metrology (QUANOMET) initiative of Lower Saxony within project NL-4.

[1] H. Rubinsztein-Dunlop, et al., Journ. Opt. 19, 013001 (2017)

TT 27.6 Fri 11:30 H7

Berry curvature-induced local spin polarisation in gated graphene/WTe_2 heterostructures — •Jonas Kiemle[1,2], Lukas Powalla[3,4], Elio J. König[3], Andreas P. Schnyder[3], Johannes Knolle[2,5], Klaus Kern[3,4], Alexander Holleitner[1,2], Christoph Kastl[1,2], and Marko Burghard[3] — [1]Walter Schottky Institut and Physics Department, Technical University of Munich, Am Coulombwall 4a, Garching — [2]MCQST, Schellingstrasse 4, München — [3]Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, Stuttgart — [4]Institut de Physique, Ecole Polytechnique Fédérale de Lausanne, Lausanne — [5]Department of Physics TQM, Technical University of Munich, James-Frank-Strasse 1, Garching

Experimental control of local spin-charge interconversion is of primary interest for spintronics. Van der Waals heterostructures combining graphene with a strongly spin-orbit coupled two-dimensional (2D) material enable such functionality by design. Here, we probe the gate-tunable local spin polarisation in current-driven graphene/WTe_2 heterostructures through magneto-optical Kerr microscopy. We observe, that even for a nominal in-plane transport, substantial out-of-plane spin accumulation is induced by a corresponding out-of-plane current flow [1]. Our findings unravel the potential of 2D heterostructure engineering for harnessing topological phenomena for spintronics, and constitute an important step toward nanoscale, electrical spin control.

[1] L. Powalla, J. Kiemle et al., arXiv:2106.15509 (2021)

TT 27.7 Fri 11:45 H7

Impact of domain disorder on optoelectronic properties of semimetal $MoTe_2$ — •Maanwinder Partap Singh[1,2], Jonas Kiemle[1,2], Philipp Zimmermann[1,2], Marko Burghard[3], Christoph Kastl[1,2], and Alexander Holleitner[1,2] — [1]Walter Schottky Institut and Physics Department, Technical University of Munich, Am Coulombwall 4a, 85748 Garching, Germany. — [2]Munich Center of Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany. — [3]Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-70569 Stuttgart, Germany.

$MoTe_2$, one of the candidates to realize the topological type-II Weyl semimetal, crystallizes in several structures. At room temperature, $Mote_2$ can have either a semiconducting (2H) or a metallic phase (1T'). Upon cooling, the monoclinic phase undergoes a transition at ~ 240 K into an orthorhombic phase (T_d), which breaks the inversion symmetry. We investigate the optoelectronic properties of $MoTe_2$ as a function of temperature using photocurrent spectroscopy in combination with Raman and transient reflection spectroscopy. We elucidate the impact of phase disorder on the generation of local photocurrents especially with respect to ultrafast photogalvanic currents [1].

[1] Singh et al. (submitted)(2021)

TT 27.8 Fri 12:00 H7

2D-Berry-curvature-driven large anomalous Hall effect in layered topological nodal-line MnAlGe — •Satya N. Guin and Claudia Felser — Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

Topological magnets comprising two-dimensional (2D) magnetic layers with Curie temperatures (TC) exceeding room temperature are key for dissipationless quantum transport devices. However, the identification of a material with 2D ferromagnetic planes that exhibits an out-of-plane-magnetization remains a challenge. We report a ferromagnetic, topological, nodal-line, and semimetal MnAlGe composed of square-net Mn layers that are separated by nonmagnetic Al-Ge spacers. The 2D ferromagnetic Mn-layers exhibit an out-of-plane magnetization below TC 503 K. Density functional calculations demonstrate that 2D arrays of Mn atoms control the electrical, magnetic, and therefore topological properties in MnAlGe. The unique 2D distribution of the Berry curvature resembles the 2D Fermi surface of the bands that formed the topological nodal line near the Fermi energy. A large anomalous Hall conductivity (AHC) of 700 S/cm is obtained at 2 K and related to this nodal line-induced 2D Berry curvature distribution. The high transition temperature, large anisotropic out-of-plane magnetism, and natural hetero-structure-type atomic arrangements consisting of magnetic Mn and non-magnetic Al/Ge elements render nodal-line MnAlGe one of the few, unique, and layered topological ferromagnets that have ever been observed.

[1] S. N. Guin et al., Adv. Mater. 2021, 33 (21), 2006301

TT 27.9 Fri 12:15 H7

A quantum oscillation study in the Dirac nodal-line semimetal HfSiS — •Claudius Müller[1], Jasper Linnartz[1], Leslie Schoop[2], Nigel Hussey[1,3], and Steffen Wiedmann[1] — [1]High Field Magnet Laboratory (HFML-EMFL), IMM, Radboud University, Nijmegen, the Netherlands — [2]Department of Chemistry, Princeton University, Princeton, New Jersey, USA — [3]H. H. Wills Physics Laboratory, University of Bristol, Bristol, UK

We have performed a de Haas - van Alphen (dHvA) quantum oscillation study of HfSiS in high magnetic fields up to 31 T. For parallel alignment of the magnetic field and the c-axis, we observe quantum oscillations originating from individual electron and hole pockets, as well as oscillations caused by magnetic breakdown (MB) between these pockets. The MB orbits come in a wide variety, ranging from a so-called 'figure-of-eight' orbit to orbits enclosing large areas in the Brillouin zone (BZ). These MB orbits can be seen as a manifestation of Klein tunneling in momentum space [1], although in a regime of partial transmission due to the finite separation between adjacent pockets. Our experimental observation, the strong dependence of the oscillation amplitude on the field angle and the cyclotron masses of the MB orbits, is in good agreement with the theoretical predictions for this novel tunneling phenomenon.

[1] M. van Delft et al., Phys. Rev. Lett. 121, 256602 (2018)

TT 27.10 Fri 12:30 H7

Magnetic breakdown and open orbits in $LaIn_3$ — •Jasper Linnartz[1], Davide Pizzirani[1], Claudius Müller[1], Sam Teicher[2], Ratnadwip Singha[3], Sebastiaan Klemenz[3], Leslie Schoop[3], and Steffen Wiedmann[1] — [1]High Field Magnet Laboratory (HFML-EMFL), IMM, Radboud University, Nijmegen, the Netherlands — [2]Materials Department and California Nanosystems Institute, University of California Santa Barbara, Santa Barbara, USA — [3]Department of Chemistry, Princeton University, Princeton, USA

$LaIn_3$ which crystalizes in the $AuCu_3$ structure provides is a highly tunable system for emergent phenomena in condensed matter such as a monotonic increase of its critical temperature upon Sn doping. It is also considered as a model system for the heavy fermion systems $CeIn_3$ and $PrIn_3$.

We present a systematic de Haas-van Alphen quantum oscillations study on $LaIn_3$ up to 30 T. By measuring the temperature and angle dependence, the Fermi surface and the charge carrier properties such as the effective cyclotron masses are determined. While the finding of some pockets of the complex Fermi surface is in agreement with theoretical predictions, the observation of various high-frequency oscillations at specific angles points towards field-induced magnetic breakdown that can be described in a two-dimensional network of open orbits.

TT 28: Transport (joint session TT/DY)

Time: Friday 13:30–15:00 Location: H6

TT 28.1 Fri 13:30 H6

Spin-relaxation in superconducting graphene systems — •Michael Barth, Jacob Fuchs, Andreas Costa, Klaus Richter, Jaroslav Fabian, and Denis Kochan — Universität Regensburg

The spin-relaxation time τ_s is a fundamental quantity as it determines how long spins can propagate before they relax. For quasi-particles in s-wave superconductors that scatter off magnetic impurities this quantity is expected to decrease by lowering the temperature, known as the Hebel-Slichter-effect [1]. We have shown that this decrease of the spin-relaxation time does not happen generally in all superconductors [2]. A completely opposite behavior can be observed, if Yu-Shiba-Rusinov (YSR) states develop deeply inside the superconducting gap, since then the magnetic moments energetically decouple from the coherence peaks what in turn weakens an exchange interaction with quasi-particles. By employing analytical and numerical methods we have shown that such deep lying in-gap YSR states are formed if a system with magnetic impurities is doped to resonances. As an explicit example we will present results for graphene and bilayer graphene decorated with light magnetic impurities as hydrogen and fluorine.

[1] L. C. Hebel and C. P. Slichter, Phys. Rev. 113, 1504 (1959)
[2] D. Kochan, M. Barth, A. Costa, K. Richter, J. Fabian, Phys. Rev. Lett. 125, 087001 (2020)

TT 28.2 Fri 13:45 H6

Aharonov-Bohm Oscillations in Minimally Twisted Bilayer Graphene — Christophe De Beule[1], Fernando Dominguez[2], and •Patrik Recher[2,3] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg — [2]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [3]Laboratory for Emerging Nanometrology, 38106 Braunschweig, Germany

We investigate transport in the network of valley Hall states that emerges in minimally twisted bilayer graphene under interlayer bias. To this aim, we construct a scattering theory that captures the network physics. In the absence of forward scattering, symmetries constrain the network model to a single parameter that interpolates between one-dimensional chiral zigzag modes and pseudo-Landau levels. Moreover, we show how the coupling of zigzag modes affects magnetotransport. In particular, we find that scattering between parallel zigzag channels gives rise to Aharonov-Bohm oscillations that are robust against temperature, while coupling between zigzag modes propagating in different directions leads to Shubnikov-de Haas oscillations that are smeared out at finite temperature.

TT 28.3 Fri 14:00 H6

Spin interference effects in quantum rings in the presence of SU(2) fields — Alberto Hijano[1,2,3], Tineke van den Berg[3], Diego Frustaglia[4], and •Dario Bercioux[3,5] — [1]University of the Basque Country, UPV/EHU, Bilbao, Spain — [2]Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU, E-20018 Donostia-San Sebastián, Spain — [3]Donostia International Physics Center, Paseo Manuel de Lardizbal 4, E-20018 San Sebastián, Spain — [4]Departamento de Física Aplicada II, Universidad de Sevilla, E-41012 Sevilla, Spain — [5]IKERBASQUE, Basque Foundation of Science, 48011 Bilbao, Spain

We present a theory of conducting quantum networks that accounts for Abelian and non-Abelian fields acting on spin carriers [1]. We apply this approach to model the conductance of mesoscopic spin interferometers of different geometry (such as squares and rings), reproducing recent experimental findings in nanostructured InAsGa quantum wells subject to Rashba spin-orbit and Zeeman fields [2,3] (as, e.g., the manipulation of Aharonov-Casher interference patterns by geometric means). Moreover, by introducing an additional field-texture engineering, we manage to single out a previously unnoticed spin-phase suppression mechanism. Our approach can also be used for the study of complex networks and the spectral properties of closed systems.

[1] Hijano *et al.*, Phys. Rev. B **103**, 155419 (2021)
[2] Nagasawa, *et al.*, Nat. Commun. **4**, 2526 (2013)
[3] Wang *et al.*, Phys. Rev. Lett. **123**, 266804 (2019)

TT 28.4 Fri 14:15 H6

Length dependent symmetry in narrow chevron-like graphene nanoribbons — •Koen Houtsma[1], Mihaela Enache[1], Remco Havenith[1,2], and Meike Stöhr[1] — [1]Zernike Institute for Advanced Materials, University of Groningen, 9747AG Groningen, the Netherlands — [2]Stratingh Institute for Chemistry, University of Groningen, 9747AG Groningen, the Netherlands

Graphene nanoribbons (GNRs) are an exciting material due to their excellent and tunable electronic properties. For instance, GNRs with armchair edges possess a width-dependent band gap, whereas zigzag GNRs are expected to host spin-polarized edge states and be semimetallic [1]. Previously, narrow chevron-like GNRs, which host a combination of zigzag and armchair edge terminations, were fabricated on a Au(111) substrate from the prochiral precursor 6,12-dibromochrysene through a combination of Ullmann-type coupling and cyclodehydrogenation [2]. Depending on the number of monomer units the ribbons are made of, an even and an odd number lead to a mirror and a point symmetric ribbon, respectively. Using scanning tunneling spectroscopy we investigated the potential effect of this length dependent symmetry on the electronic properties. In addition, bends are formed in these ribbons through a common coupling defect. We characterized these bends using a combination of high-resolution scanning tunneling microscopy and spectroscopy. The bends are based on the formation of both a five- and six-membered ring and their electronic properties are altered.

[1] K. Nakada et al., Phys. Rev. B 54, 17954 (1996)
[2] T.A. Pham et al., Small 13, 1603675 (2017)

TT 28.5 Fri 14:30 H6

Thermal fluctuations of two-dimensional crystalline membranes: a scale-invariant but nonconformal field theory — •Achille Mauri and Mikhail I. Katsnelson — Radboud University, Institute for Molecules and Materials, Nijmegen, The Netherlands

Statistical fluctuations of two-dimensional membranes have been the subject of extensive investigations, from string theories to biological and condensed matter systems such as graphene and other atomically-thin 2D materials. In the case of solid layers subject to vanishing external tension, the interplay of thermal fluctuations and anharmonic phonon-phonon interactions gives rise to a crucial renormalization of the elastic constants: as a result, the long-wavelength behavior of phonon fluctuations is scale-invariant and it is controlled by an interacting fixed point of the renormalization group (RG). In this contribution, we argue that, in contrast with several other field-theories, the emergent dilatation symmetry is not enhanced to the full conformal invariance. We analyze in particular, the structure of the energy-momentum tensor $T_{\mu\nu}$ within an ϵ-expansion, after extension of the problem from the physical dimension $D = 2$ to a non-integer dimensionality $D = 4 - \epsilon$. The trace $T_{\mu\mu}$ reduces, at the fixed point, to the total divergence of a non-trivial virial current, implying the absence conformal invariance.

TT 28.6 Fri 14:45 H6

Viscous, elastic and ballistic shear response of electron fluids probed through optical spectroscopy — •Davide Valentinis[1,2], Jan Zaanen[3], Dirk van der Marel[4], and Joerg Schmalian[1,2] — [1]Institut für Quantenmaterialien und Technologien, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstra{\ss}e 1, D-70569 Stuttgart (DE) — [3]Department of Quantum Matter Physics, University of Geneva, 24 Quai Ernest-Ansermet, 1211 Geneva 4, Switzerland — [4]Institute-Lorentz for Theoretical Physics, Leiden University, PO Box 9506, NL-2300 RA Leiden, The Netherlands

Can optical spectroscopy provide complementary and unambiguous fingerprints of spatial nonlocality in bulk and layered materials, and under which conditions? To answer these questions, we investigate the nonlocal current response of 3D charged Fermi liquids, and 2D isotropic and anisotropic metals, taking into account momentum-conserving collisions and momentum-relaxing scattering in kinetic-theory approaches. In strongly interacting Fermi liquids, a propagating shear mode of Fermi-surface deformation, analogous to transverse sound in liquid helium, determines characteristic oscillating patterns of the thin-film transmission as a function of radiation frequency. We develop a kinetic theory for the distribution function of 2D Fermi gases with arbitrary electronic dispersion relation, using a collision operator formalism. The skin depth and surface impedance are shown to qualitatively depend on the shape and orientation of the polygonal Fermi surface.

TT 29: Topological Superconductors

Time: Friday 13:30–15:00 Location: H7

TT 29.1 Fri 13:30 H7

Doping a topological insulator: a promising strategy to find topological superconductors? — Sebastian Wolf, Tylor Gardener, and •Stephan Rachel — School of Physics, University of Melbourne, Parkville, VIC 3010, Australia

The search for topological superconductors is one of the most pressing and challenging questions in condensed matter and material research. Despite some early suggestions that doping a topological insulator might be a successful recipe to find topological superconductors, until today there is no general understanding of the relationship of the topology of the superconductor and the topology of its underlying normal state system. One of the major obstacles is the strong effect of the Fermi surface and its subsequent pairing tendencies, usually preventing a detailed comparison between different topological superconducting systems. Here we present an analysis of various doped insulators-topological and trivial–for which the differences of the Fermi surfaces have been removed. Our approach allows us to analyze and compare superconducting instabilities of different insulating normal state systems with identical Fermi surfaces and to present rigorous results on how beneficial it might be to dope a topological insulator.

TT 29.2 Fri 13:45 H7

Accidental Two-Component Order Parameter in UTe_2 — •Florian Theuss[1], Gael Grissonnanche[1], Nicholas Butch[2,3], Johnpierre Paglione[3], Sheng Ran[4], Kelly Nygren[5], Peter Ko[5], and Brad Ramshaw[1] — [1]Cornell University, Ithaca, NY, USA — [2]NIST, College Park, MD, USA — [3]University of Maryland, College Park, MD, USA — [4]Washington University, St. Louis, MO, USA — [5]CHESS, Ithaca, NY, USA

The recently discovered unconventional superconductor UTe_2 is a promising candidate to host time-reversal symmetry breaking (TRSB) in the ordered state, below about 1.6 K. TRSB, indicated by a field trainable Kerr effect, would require a two-component order parameter. Due to the orthorhombic crystal symmetry of UTe_2, a two-component order parameter is expected to be accidental, resulting in two successive superconducting phase transitions. We address this question with Resonant Ultrasound Spectroscopy, where we measure mechanical resonance frequencies of the sample and can resolve two jumps in their temperature dependence with close to part per million resolution. This gives us information about the possibility of a two-component order parameter and constrains its symmetry. Additionally, we perform near-field/far-field high-energy X-ray diffraction experiments to investigate sample homogeneity.

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TT 29.3 Fri 14:00 H7

Sub-gap and supra-gap transport characteristics of the finite Kitaev chain — •Nico Leumer[1], Milena Grifoni[1], Bhaskaran Muralidharan[2], and Magdalena Marganska[1] — [1]Institute for Theoretical Physics, University of Regensburg, Germany — [2]Department of Electrical Engineering, Indian Institute of Technology Bombay, India

We investigate the nonlinear transport in a normal - Kitaev chain- normal (N-K-N) junction. Using exact analytical results for the spectrum and Green's function of the Kitaev chain in the whole regime of parameters, an exact expression for the linear conductance is provided, and insight into the complex interplay of crossings and anticrossings in the supra-gap region is obtained. In particular, we discuss how the ratio of the direct charge transfer and the local Andreev reflection relates to the spatial profile of the lowest lying state. Also, we demonstrate that the supra-gap transport shows stable and strong contributions from the local Andreev reflection which yields the same contribution as the direct processes at the anti-crossing [1].

[1] N. Leumer, M. Grifoni, B. Muralidharan, M. Marganska, Phys. Rev. B, **103**, 165432 (2021)

TT 29.4 Fri 14:15 H7

2π Domain Walls for Tunable Majorana Devices — •Daniel Hauck[1], Stefan Rex[2,3], and Markus Garst[1] — [1]Karlsruhe Institute of Technology, Institute for Theoretical Solid State Physics, Wolfgang-Gaede-Str. 1, 76131 Karlsruhe — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [3]Institute for Theoretical Condensed Matter Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe

Superconductor-magnet hybrid structures provide a platform for investigating topological phases with localized Majorana states. Such states have previously been predicted for elongated Skyrmions in the magnetic layer. Here we consider 2π domain walls that can be easily controlled experimentally. Depending on the boundary conditions, we demonstrate that localized Majorana states can be found at both ends of such walls. This establishes 2π domain walls as tunable elements for the realization of Majorana devices.

TT 29.5 Fri 14:30 H7

Majorana Bound States Induced by Antiferromagnetic Skyrmion Textures — •Sebastián A. Díaz[1,2], Jelena Klinovaja[2], Daniel Loss[2], and Silas Hoffman[3,2] — [1]Faculty of Physics, University of Duisburg-Essen, Duisburg, Germany — [2]Department of Physics, University of Basel, Basel, Switzerland — [3]Department of Physics, University of Florida, Gainesville, USA

Majorana bound states are zero-energy states predicted to emerge in topological superconductors and intense efforts seeking a definitive proof of their observation are still ongoing. A standard route to realize them involves antagonistic orders: a superconductor in proximity to a ferromagnet. Here, we show that this issue can be resolved using antiferromagnetic rather than ferromagnetic order. We propose to use a chain of antiferromagnetic skyrmions, in an otherwise collinear antiferromagnet, coupled to a bulk conventional superconductor as a novel platform capable of supporting Majorana bound states that are robust against disorder. Crucially, the collinear antiferromagnetic region neither suppresses superconductivity nor induces topological superconductivity, thus allowing for Majorana bound states localized at the ends of the chain. Our model introduces a new class of systems where topological superconductivity can be induced by editing antiferromagnetic textures rather than locally tuning material parameters, opening avenues for the conclusive observation of Majorana bound states.

[1] S. A. Díaz, J. Klinovaja, D. Loss, S. Hoffman, arXiv:2102.03423

TT 29.6 Fri 14:45 H7

Interaction-Stabilized Topological Magnon Insulator in Ferromagnets — •Alexander Mook, Kirill Plekhanov, Jelena Klinovaja, and Daniel Loss — University of Basel, Basel, Switzerland

Condensed matter systems admit topological collective excitations above a trivial ground state, an example being Chern insulators formed by Dirac bosons with a gap at finite energies. However, in contrast to electrons, there is no particle-number conservation law for collective excitations, which gives rise to particle-number-nonconserving many-body interactions whose influence on single-particle topology is an open issue of fundamental interest in the field of topological quantum materials.

Taking magnons in ferromagnets as an example, we uncover topological magnon insulators that are stabilized by interactions through opening Chern-insulating gaps in the magnon spectrum. This finding can be traced back to the fact that the particle-number nonconserving interactions break the effective time-reversal symmetry of the harmonic theory. Hence, magnon-magnon interactions are a source of topology that can introduce chiral edge states. Importantly, interactions do not necessarily cause detrimental damping but can give rise to topological magnons with exceptionally long lifetimes. Our results demonstrate that particle-number-nonconserving many-body interactions play an important role in generating nontrivial single-particle topology.

[1] A. Mook, K. Plekhanov, J. Klinovaja, D. Loss, Phys. Rev. X 11, 021061 (2021)